C M Butler

OCTOBER, 1916 BULLETIN 382

CORNELL UNIVERSITY
AGRICULTURAL EXPERIMENT STATION

SUN-SCALD OF FRUIT TREES
A TYPE OF WINTER INJURY

A. J. MIX

ITHACA, NEW YORK
PUBLISHED BY THE UNIVERSITY

OCTOBER, 1916 BULLETIN 382

CORNELL UNIVERSITY
AGRICULTURAL EXPERIMENT STATION

SUN-SCALD OF FRUIT TREES
A TYPE OF WINTER INJURY

A. J. MIX

ITHACA, NEW YORK
PUBLISHED BY THE UNIVERSITY

CORNELL UNIVERSITY

AGRICULTURAL EXPERIMENT STATION

Experimenting Staff

ALBERT R. MANN, B.S.A., A.M., Acting Director.
HENRY H. WING, M.S. in Agr., Animal Husbandry.
T. LYTTLETON LYON, Ph.D., Soil Technology.
JOHN L. STONE, B.Agr., Farm Practice.
JAMES E. RICE, B.S.A., Poultry Husbandry.
GEORGE W. CAVANAUGH, B.S., Agricultural Chemistry.
HERBERT H. WHETZEL, M.A., Plant Pathology.
ELMER O. FIPPIN, B.S.A., Soil Technology.
G. F. WARREN, Ph.D., Farm Management.
WILLIAM A. STOCKING, Jr., M.S.A., Dairy Industry.
WILFORD M. WILSON, M.D., Meteorology.
RALPH S. HOSMER, B.A.S., M.F., Forestry.
JAMES G. NEEDHAM, Ph.D., Entomology and Limnology.
ROLLINS A. EMERSON, D.Sc., Plant Breeding.
HARRY H. LOVE, Ph.D., Plant Breeding.
ARTHUR W. GILBERT, Ph.D., Plant Breeding.
DONALD REDDICK, Ph.D., Plant Pathology.
EDWARD G. MONTGOMERY, M.A., Farm Crops.
WILLIAM A. RILEY, Ph.D., Entomology.
MERRITT W. HARPER, M.S., Animal Husbandry.
JAMES A. BIZZELL, Ph.D., Soil Technology.
GLENN W. HERRICK, B.S.A., Economic Entomology.
HOWARD W. RILEY, M.E., Farm Mechanics.
CYRUS R. CROSBY, A.B., Entomology.
HAROLD E. ROSS, M.S.A., Dairy Industry.
KARL McK. WIEGAND, Ph.D., Botany.
EDWARD A. WHITE, B.S., Floriculture.
WILLIAM H. CHANDLER, Ph.D., Pomology.
ELMER S. SAVAGE, M.S.A., Ph.D., Animal Husbandry.
LEWIS KNUDSON, Ph.D., Plant Physiology.
KENNETH C. LIVERMORE, Ph.D., Farm Management.
ALVIN C. BEAL, Ph.D., Floriculture.
MORTIER F. BARRUS, Ph.D., Plant Pathology.
CLYDE H. MYERS, M.S., Ph.D., Plant Breeding.
GEORGE W. TAILBY, Jr., B.S.A., Superintendent of Livestock.
EDWARD S. GUTHRIE, M.S. in Agr., Ph.D., Dairy Industry.
JAMES C. BRADLEY, Ph.D., Entomology.
PAUL WORK, B.S., A.B., Vegetable Gardening.
JOHN BENTLEY, Jr., B.S., M.F., Forestry.
EARL W. BENJAMIN, Ph.D., Poultry Husbandry.
EMMONS W. LELAND, B.S.A., Soil Technology.
CHARLES T. GREGORY, Ph.D., Plant Pathology.
WALTER W. FISK, M.S. in Agr., Dairy Industry.
ARTHUR L. THOMPSON, Ph.D., Farm Management.
ROBERT MATHESON, Ph.D., Entomology.
MORTIMER D. LEONARD, B.S., Entomology.
FRANK E. RICE, Ph.D., Agricultural Chemistry.
VERN B. STEWART, Ph.D., Plant Pathology.
IVAN C. JAGGER, M.S. in Agr., Plant Pathology (In cooperation with Rochester University).
WILLIAM I. MYERS, B.S., Farm Management.
LEW E. HARVEY, B.S., Farm Management.
LEONARD A. MAYNARD, A.B., Ph.D., Animal Husbandry.
LOUIS M. MASSEY, A.B., Ph.D., Plant Pathology.
BRISTOW ADAMS, B.A., Editor.
LELA G. GROSS, Assistant Editor.

The regular bulletins of the Station are sent free on request to residents of New York State.

CONTENTS

PAGE

Observations on sun-scald injury 237
Sun-scald injury occurring in the winter of 1913–14 240
Review of American literature on sun-scald and related injuries 242
The freezing to death of plant tissue 244
Effect of rapid freezing 244
Effect of rapid thawing 245
Theories regarding the occurrence of sun-scald 246
Observations and experiments 247
Temperatures that may occur in winter on the sun-exposed parts of the trunk 247
Temperatures observed during the winter of 1914–15 250
A comparison of the date of awakening and relative hardiness of the cambial area on the northeast and southwest sides of the trunk 255
Natural injury in the winter of 1914–15 274
Relative hardiness of tissue from the crown and the upper parts of the trunk 277
Effect of freezing tissue when wet 282
Conclusion 282
Literature cited 283

SUN-SCALD OF FRUIT TREES: A TYPE OF WINTER INJURY[1]

A. J. Mix[2]

The type of winter injury to fruit trees to be discussed in this paper is the well-known injury to the southwest, or sun-exposed, side of the trunk, commonly known as sun-scald. It is usually made evident in late spring by the death of patches of bark, which often peel off and expose the sapwood, but in some cases adhere firmly to the wood, forming sunken, canker-like areas. Such dead-bark areas are often inhabited by higher fungi—wound parasites or saprophytes. One of the commonest forms following sun-scald in New York is *Physalospora Cydoniae* Arnaud. Similar injured areas are often found on the upper, sun-exposed sides of large branches. Probably these injuries are caused in the same manner as those on the trunk.

Sun-scald is so named because it is believed to be brought about by some interaction of sun and cold on the sunny side of the trunk in late winter.[3]

Two other types of injury that are somewhat closely related to sun-scald are crotch injury, occurring at the head and in the crotches of rapidly growing branches, and crown injury, or crown rot, occurring at the crown, or base, of the trunk. For the purposes of this paper the following distinction is made: Injury localized on the southwest side of the trunk, whether at the crown, at the head, or on the intermediate part, is considered typical sun-scald. Injury typically occurring at the head and in the crotches, or at the crown, without relation to the points of the compass in either case, is designated as crotch injury or crown rot, respectively. All three types of injury are herein discussed.

OBSERVATIONS ON SUN-SCALD INJURY

In the northern half of the Champlain Valley, New York, including parts of Essex and Clinton Counties, is an area lying between Lake Champlain and the Adirondack Mountains, in which some attention is given to growing apples on a commercial scale. The varieties most grown

[1] Also presented to the Faculty of the Graduate School of Cornell University, February, 1916, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

AUTHOR'S ACKNOWLEDGMENTS. Grateful acknowledgment for help and criticism is made to Professors Donald Reddick and H. H. Whetzel, and especially to Professor W. H. Chandler, under whose immediate direction the work here reported was performed.

[2] Formerly Fellow in Plant Pathology at Cornell University, now Instructor in Plant Pathology at the University of Kansas, Lawrence, Kansas.

[3] Possibly this injury would be more properly called winter sun-scald, to distinguish it from sun-scald or sun-scorch resulting from the direct action of the sun in midsummer. Considerable mention of summer sun-scald is made in literature. Hartig (1894) describes an interesting case of the injury to spruce.

are Fameuse, McIntosh, Ben Davis, Northern Spy, Rhode Island, and Wealthy. A few Baldwin orchards also are found.

The writer had occasion to spend much of his time in this locality during the summer seasons of 1913, 1914, and 1915. One of the conditions noted in the early part of the season of 1913 was the almost universal prevalence in these various orchards of trunk injury to the southwest side of the tree. This injury was not recent, but had apparently occurred one or two years earlier. The unanimous opinion of the growers was that it had occurred during the winter of 1910-11. This view was substantiated by sawing into several injured trunks and counting the number of annual rings formed since the injury.

In the summer of 1913 a careful survey was made of a number of orchards, in order to determine if possible the relation of certain factors to the amount of injury. The survey was never extended to include all the orchards in this region, and served merely to confirm conclusions that might be drawn from a somewhat casual observation. It is therefore not reproduced in any detail here, but the most evident facts gained from a study of it are stated.

There are a number of very old orchards in the lower Champlain Valley, but the majority of commercial orchards are from twenty to thirty years old. There are also many younger orchards. The injury was practically confined to orchards between the ages of eight and thirty years. None of this recent injury was observed in the very old orchards, tho evidences were found of one or more earlier injuries, the dates of which were not determined.

The injury was confined almost entirely to the southwest side of the tree. Trees leaning to the northeast were most severely injured. In one or two orchards, trees of the Ben Davis variety were found to have a number of injured places on any and all sides of the trunk.

The injury might occur at any height on the trunk, might extend from the crown to the head involving the whole of the southwest side of the trunk, or might appear at from one to several places at various heights. The commonest form, however, was an injured area beginning at a point from ten to twenty-five centimeters above the crown and extending to within a short distance below the head; in other words, the part of the trunk midway between the crown and the head was oftenest injured (Plate XVIII). Only a few cases were found in which the injury was confined to the region of the crown. A few cases of crotch injury were observed, one of the most striking being in a twenty-years-old Northern Spy orchard. The trees in this orchard were comparatively low-headed, and a large number of nearly upright main branches originated from almost the same point. In these trees the injury was chiefly in the

crotches of these branches, usually extending up along the branches themselves for a distance of several centimeters. In this orchard the injury was localized on the southwest side of the tree.

The number of injured trees in the orchards examined averaged about twenty to twenty-five per cent of the total number of trees.

No satisfactory conclusions could be drawn as to the relation of soil type, location, exposure, or previous cultural treatment of the orchard, to the amount of injury. However, there are a few orchards on extremely light, infertile soils. The trees on these soils are normally less well-grown, less vigorous, and shorter-lived than the same varieties on heavier types of soil. They were found to be much more affected by sun-scald injury. It seems probable that this is an indirect soil relation, due to the influence of the soil on the vigor of the tree.

There seemed to be a fairly well-marked range of susceptibility of varieties. Ben Davis suffered the most, Northern Spy next, and Fameuse, McIntosh, Baldwin, and Rhode Island somewhat less. Not a sufficient number of Wealthy trees were examined to warrant a statement as to the relative susceptibility of that variety.

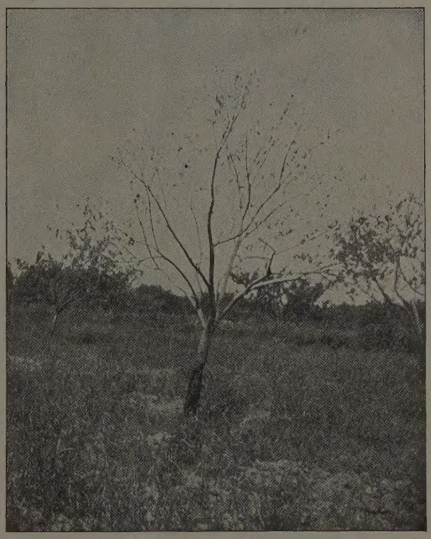


FIG. 60. BEN DAVIS APPLE TREE THE ROOTS OF WHICH WERE WINTERKILLED DURING THE WINTER OF 1913-14

Photograph made in June, 1914. This tree has also an old sun-scald injury which has been treated with gas tar

It is of interest in this connection that in the winter of 1913-14 there was in this locality a great amount of winter injury to roots of apple trees from one to twenty years of age, and in a few cases to much older trees. This injury was in many instances severe, a number of trees having their whole root system killed, and the injury often extended to the crown, killing the cambium and the outer sapwood so that the bark lifted away from the trunk around its whole circumference for a distance varying from two to six or eight inches above the soil. Fall plowing seemed to have increased the amount of this injury somewhat, and it was also more prevalent on light soils and wind-exposed locations. But the most striking

fact observed was the marked susceptibility of the Ben Davis variety. The writer could find no Ben Davis orchard that had entirely escaped injury. In many of these from fifty to seventy-five per cent of the trees were in a dying condition, and if they survived the summer of 1914 they succumbed early in 1915. (Fig. 60.) Northern Spy and Wealthy trees also suffered severely, altho not to nearly so great a degree as Ben Davis. It appears that the Ben Davis variety is not a hardy tree in the lower Champlain Valley, and it may be questioned whether Northern Spy is.

A point of horticultural interest worth mentioning in connection with this root injury is that, altho some of these Ben Davis trees were root-grafted trees, many of them, according to the owners' statement and the appearance of the trunk at the union, were originally budded trees and therefore not on their own roots. In this case the hardiness of the stock seems to have been influenced by the scion.

SUN-SCALD INJURY OCCURRING IN THE WINTER OF 1913-14

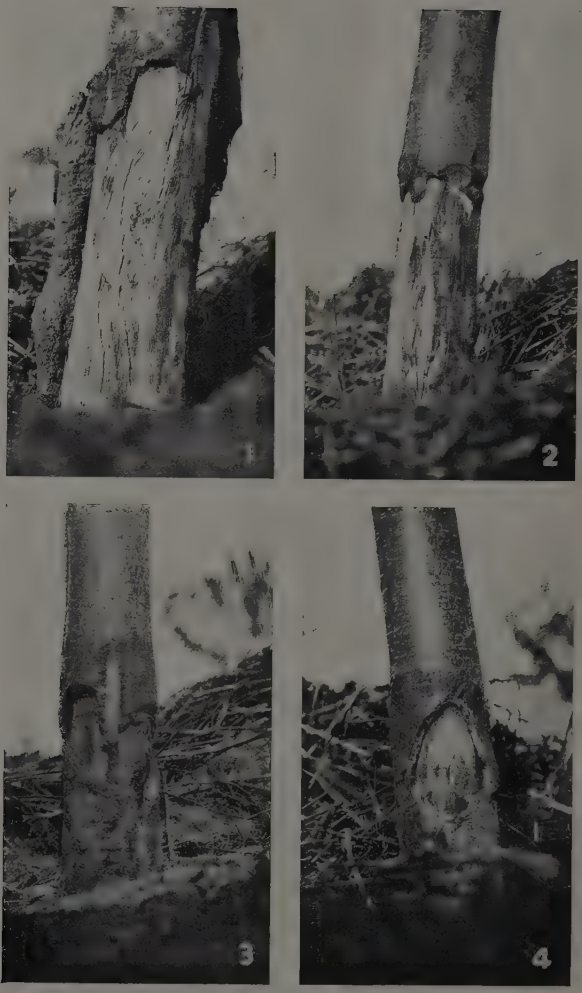
A very interesting case of sun-scald injury occurred in the orchard of W. E. Everett, at Peru, New York, during the winter of 1913-14. This is a small orchard of two hundred and sixty trees, seven years old at the time the injury occurred. The trees in the first, second, and fourth to eighth rows, or one hundred and sixty-three trees on the west side of the orchard, were mostly of the Wealthy variety; the trees in the third row, twenty-two trees, were of the Mann variety; the remaining three rows of trees, on the east side of the orchard, seventy-five trees, were Fameuse. The soil is light and gravelly, and not particularly fertile, but the trees had been well manured, cultivated, and sprayed, and were fairly well grown and vigorous. The soil was somewhat better in the western half of the orchard, and the trees there were slightly larger. The injury was much severer in this part of the orchard. It was thought that this indicated a less degree of hardiness of the Wealthy variety, but no definite conclusion could be drawn.

Late in the summer of 1913, the owner, in the hope of protecting his trees against the attack of borers, painted the trunks with gas tar for a distance of about one foot from the ground. Several rows of trees, two or three years younger and of an unknown variety, to the west of the Fameuse, were not so painted. The injury was confined entirely to the trees that were painted, and the injury to each was confined to the blackened part of the trunk.

The injury was first noted on April 30, 1914, and a brief examination of it was then made, followed by a more careful examination of every affected tree a short time later. The bark was found to be loosened from the wood, and the sapwood and the cambial area were discolored

OLD SUN-SCALD INJURIES OBSERVED IN THE LOWER CHAMPLAIN VALLEY IN THE SUMMER OF 1913

Photographs taken in August, 1915



SUN-SCALD INJURY TO TARRED TRUNKS OF APPLE IN WINTER OF 1913-14
Photographs taken in August, 1914, after the dead bark had been trimmed away

dark brown; but the bark itself was green and apparently alive. The injury could not have been due to the direct action of the gas tar on the tissue, since only the very outer bark showed any injurious effect from the tar, the inner bark being normal in color and appearance.

Of the two hundred and sixty trees in this orchard, one hundred and eleven were injured to some extent; on sixty-five of these the bark was loosened from the wood for one-third of the circumference or more; on eight of the latter the bark was loosened thruout the entire circumference or nearly so, in some cases a very narrow strip of uninjured wood and bark being found on the northeast side. Three trees had their bark loosened from the trunk all the way around.

In cases in which the bark was loosened thruout the whole circumference or nearly so, it was usually split open in one or more places. Most of these splits were on the southwest side of the trunk. In less severe cases the localization on this side was even more marked; where the bark was loosened for a space of from one-third to two-thirds of the circumference this loosened area was invariably on the southwest or the west side. In the case of the forty-six trees showing less severe injury, this injury consisted of small to large areas on the southwest side of the trunk, where the bark was lifted from the wood.

The above-mentioned facts point to the conclusion that the injury was of the sun-scald type and that the application of gas tar was the indirect cause of its occurrence. The black color probably caused the tissue of the bark to absorb more than the normal amount of heat, so that proper conditions for the occurrence of sun-scald were brought about. This unusual rise in temperature undoubtedly did not occur on unblackened trees. No cases of sun-scald on trees whose trunks were not treated with gas tar were found to have occurred in this region during the winter of 1913-14. Some observations are reported later in this paper on the temperatures that may occur in blackened trunks.

The cambium in some of these injured trees was capable of regeneration, and wound tissue was formed during the summer on the inside of the bark; but of course this made no union with the wood, and was of no apparent help in preserving the life of the tree. In cases of severe injury the formation of this thick callous layer caused the bark to split open and roll away, exposing the wood (Plate XIX, 1). In cases in which only a small area of bark was loosened, healing took place in the normal manner from the edges of the wound. The most severely injured trees either died late in the summer of 1914 or were removed by the owner in the spring of 1915. Photographs of some of these injured trunks are shown in Plate XIX.

REVIEW OF AMERICAN LITERATURE ON SUN-SCALD AND RELATED INJURIES

The first mention of sun-scald injury in this country is by Burrill (1887).[4] He describes a crown injury which is commonest on the sunny side of the trees. His explanation is as follows: Late growth, induced by a warm, moist autumn following a period of drouth, causes severe winter injuries in trees. These occur mechanically by freezing of the relatively large quantities of water in the cambial region; ice formation, together with shrinkage of the tissues, causes the bark to be pushed away from the wood.

Selby (1897) describes a local blighting of branches and trunk of apples and pears, known as sun-scald. It occurs most commonly on the west and southwest sides of trees, and trees leaning to the northeast suffer the most. Baldwin, Oldenburg, and King are listed as susceptible varieties.

Selby (1900) again mentions the occurrence of an injury of this sort to the southwest side of the tree. Grimes, King, and other varieties were severely injured.

Stewart, Rolfs, and Hall (1900) describe a case of "King disease" believed to be due to winter injury. The bark at the base of the trunk is dead and loose or fallen away; the injury extends from one to two feet up the trunk, occasionally up to the crotch, and is common on the southwest side but not confined to that side. Similar injuries are described as occurring on peach, apricot, and plum.

Clinton (1904) describes an injury to apple trees from four to eight years old which seems to be crown rot. It consists of dead areas in the bark at the base of the tree, most frequently on the north side, sometimes completely girdling the tree. Sudden zero weather on December 9, 1903, following an open fall, was believed to be the cause.

The same author (1905) describes similar injuries occurring in 1904. The injury was to the bark at the base of the trunk, often on one side but in some cases the trees were girdled. Isolated dead areas were found farther up the trunk. Young trees suffered the most. It is stated that late cultivation and excessive fertilization allow the trees to enter the winter in an unripened condition, rendering them more susceptible to winter injury.

Clinton again (1908) notes a "collar girdling" of peach trees due to winter injury, probably caused by the severe winter of 1907-08 in connection with the drouth of the previous summer which weakened the trees.

Macoun (1908) describes ten different types of winter injury occurring in Canada. Among these are the following:

Bark splitting, which is found usually on young trees. It is due to expansion, occurring when the trees have grown late and are succulent and there is a heavy fall of snow

[4] Dates in parenthesis refer to literature cited, page 283.

before the soil freezes. The snow softens the bark, and when the temperature falls suddenly the moisture in or under the bark expands in freezing and loosens the bark from the trunk or kills the cambium. Crown rot of the Gravenstein in Nova Scotia is probably the same injury.

Sun-scald, an injury common in northern and northeastern Ontario and Quebec. It occurs on the south and the southwest side of the trunk. The bark becomes unhealthy, dies, dries up, and falls away. The injury occurs in late winter or early spring, when warm days are followed by cool nights. It is the same as is found when frozen plants are thawed out suddenly, and is caused by constant alternate thawing and freezing.

Crotch injury, in which case the bark is dead in the crotch or on branches diverging from it. The injury is probably due to the lodging of ice in the crotch. The theory has been advanced that this ice acts as a lens in focusing the sun's rays, but the position of the limbs does not favor this view. It is more probable that the injury is due to softening of the bark by melted snow or water before freezing; the bark is also probably more tender at this point.

Selby (1908) describes injuries due to the October freeze of 1906. Trunk injuries were on the most exposed sides of the tree, the location of which varied in different localities. Late growth occurred in 1906. August and September were very warm, with a heavy rainfall. These conditions were succeeded by a severe cold period from October 10 to October 13.

The same author describes sun-scald as a common injury on the south and southwest sides of the trunk, and states that the severe midwinter temperatures of 1906-07 were the cause of the injury in that season. The occurrence of sun-scald is thus explained (page 135 of reference cited): "The temperature rise upon these sun-exposed surfaces is larger than upon less exposed portions, and accordingly the danger of stimulus to untimely activity of the living layer is much greater upon the heated side."

Morse (1909) notes that crotch injury was common following the winter of 1906-07. This injury is thought to be due to the loading of the crotches with soft snow, which alternately thawed and froze suddenly for two days in succession. The crotches would thus be filled with greater or less deposits of ice, which would radiate heat more rapidly than the parts not so covered.

Grossenbacher (1909) studied some cases of winter injury in western New York and in the Hudson Valley. The studies were made in 1909 and the injuries were then several years old. They were all of the crown rot type, occurring at the base of the tree with no reference to the points of the compass.

The same author (1912) reports studies of injuries that occurred in various parts of New York State, the majority of them in the winter of 1910-11. These injuries were in most cases to the crown of the tree. Where less than complete girdling occurred, Grossenbacher found a localization of the injury corresponding to the maximum wind exposure and the presumable direction of the prevailing wind at the time of injury. He records two other cases of injury that may be considered of sun-scald

type: an injury to the southwest side of the trunks of young maples in a park near Geneva, during the winter of 1909-10; and a similar injury to young apple trees at Clyde whose trunks had been surrounded by veneer protectors, during the winter of 1910-11.

Grossenbacher ascribes the cause of crown rot to low temperatures accompanied by bark tensions set up by the swaying of trees in the wind. Rapid evaporation caused by high winds is believed to be a contributory factor. High bark tensions set up by rapid growth at crown and crotch are thought to have some effect in causing the localization of injury at these points.

Grossenbacher reports an experiment in which he thawed the bark of a tree with hot water, on a January day when the air temperature was −26° C., and swayed the tree vigorously for about a minute. Water was also poured on the crotch of a tree that was not swayed. In March the bark on these trees was found to be dead. As Chandler (1913) has pointed out, this injury was probably due to a rapid temperature fall, and was not, as Grossenbacher believes, influenced by the tensions set up by swaying the tree.

Chandler (1913) found that the tissue at the base of the trunk and at the crotches becomes hardy in the fall more slowly than does that of the upper parts of the trunk, of the secondary branches, or of the twigs, and suggests that this is the probable explanation of the localization of injury at these points.

THE FREEZING TO DEATH OF PLANT TISSUE

It seems desirable at this point to state the manner in which the killing of plant tissue by freezing is supposed to occur. The work of Goeppert (1830), Müller-Thurgau (1880), and Molisch (1897) indicates that the withdrawal of water during the freezing process to form intercellular ice crystals causes the death of the cells. Without considering theories advanced by later workers to account more exactly for the death of the protoplasm, it is sufficient for the purposes of this paper to state that when, during the freezing process, water withdrawal from a cell passes a certain limit, the cell is killed.

EFFECT OF RAPID FREEZING

Winkler (1913) found that dormant buds on the twigs of various trees that were killed if frozen twelve hours at −22° C., were not killed if kept three days at −16°, two days at −18°, three days at −20°, two days at −22°, and finally twelve hours at −25°; some remained alive even at −30°.

Chandler (1913), working with winter twigs and buds of various fruit trees, found that the rapidity of the freezing process is a factor influencing

the killing. Tissue frozen rapidly (one and one-half hours to the minimum) was killed at a temperature three or four degrees higher than the same tissue when subjected to a slow (seven and one-half hours to the minimum) rate of temperature fall. Not so marked a difference was found in the case of succulent plants. Chandler found further that rapid temperature fall was much more injurious in the first part of the freezing period (from 0 to −12° C.) than in the latter part.

EFFECT OF RAPID THAWING

It was held by earlier workers that the injurious effect of freezing on plant tissue was not due to the freezing itself but to rapid thawing.

Goeppert (1830) was the first real advocate of the view that the injury is caused by the freezing process and is independent of the rate of thawing. This opinion was based on a large amount of experimental work.

Sachs (1860) conducted some experiments from which he concluded that the amount of killing was directly dependent on the rate of thawing; with plants frozen to a given temperature, those that were thawed rapidly were killed in a greater proportion than those that were thawed gradually.

Müller-Thurgau (1886), in a long series of experiments conducted with a variety of plants, found no proof that slow thawing acted to prevent injury; if the plant was killed, either rate of thawing showed it killed; if uninjured at the end of the slow-thawing process, it was also uninjured by rapid thawing.

It is interesting that Sachs' method of slow thawing was to place the frozen plants in cold water. Müller-Thurgau has pointed out that this was in reality a more rapid method than thawing in air. When the frozen plants are placed in water, a layer of ice immediately forms on their exterior, giving off heat to the tissue and consequently warming it.

Molisch (1897) conducted a large number of experiments on the effect of rapid thawing, with results similar to those obtained by Müller-Thurgau. He found a slight benefit from slow thawing in the case of fruits of apple and pear, and leaves of *Agave americana* L. With these tissues a slight further reduction in temperature was sufficient to kill, regardless of the rate of thawing.

Chandler (1913), working with a number of different plants, found no benefit from slow thawing except in the case of lettuce, and ripe fruits of apple and pear. With these tissues only a slight further reduction of temperature was needed to offset entirely the effect of slow thawing. Chandler was unable to find that increased rate of evaporation during the thawing process had any effect on the killing.

It seems strange, in view of the excellent work of Müller-Thurgau, that the idea has continued so prevalent that rapid thawing causes the

death of frozen plants, and that the same plants if thawed slowly would be saved. Perhaps it is due to the wide influence Sachs has had on later botanists, and to the possibility that his work may have been more widely read than that of Müller-Thurgau. Since the publication of Chandler's work there should be no reason for any one to adhere to this view.

Special emphasis is laid on this point, since the prevailing idea regarding the occurrence of sun-scald is that it is due to rapid thawing of the tissue on the sun-exposed side of the tree on a day of extreme cold in late winter. It is proposed in this paper to discard this hypothesis at the outset as untenable.

THEORIES REGARDING THE OCCURRENCE OF SUN-SCALD

Previous to the time of Müller-Thurgau's work in 1886, sun-scald was commonly believed to be due to rapid thawing of the frozen tissue, brought about by the action of the sun. This view has also had many adherents since that time.

Müller-Thurgau mentions the injury as one often occurring on the sunny side of trees, and places in the same category common winter injuries to needles on the south side of coniferous trees, and the protection from winter injury afforded trees and shrubs which grow on the north side of buildings.

Müller-Thurgau's explanation of the occurrence of sun-scald is as follows: Metabolic changes in the plant go on in winter under the influence of high temperatures. On sunny days in winter the bark on the south side of the tree is ten centigrade degrees or more warmer than it is on the north side. The tissue on the south side will be farther out of the rest condition and thus be more sensitive to cold. Flowers of Thuja are farther developed by the end of February than in December, and are also farther along on the south side than on the north side of the tree.

Müller-Thurgau found the moisture content of the bark slightly higher on the south than on the north side of the tree in late winter. He found also that the temperature of the bark was sometimes much higher on the sunny side.

If the view expressed above is not accepted, there remains the possibility that the tissue on the southwest side of the trunk may become tenderer in late winter due to repeated alternate freezings and thawings. Winkler (1913) found that by subjecting the twigs of several deciduous trees to repeated freezings and thawings he rendered them more susceptible to injury by freezing. Since the tissue on the southwest side of a tree trunk must be subjected to more repeated freezings and thawings than the tissue on the northeast side, it is possible that it may thus become tenderer.

Chandler (1913), from the results obtained in the comparison of the effects of rapid and of slow freezing, has suggested another possibility. On a cold, sunny day in late winter, the tissue on the sun-exposed side of a tree may become thoroly thawed out while that on the opposite side remains at or near the atmospheric temperature, which may be very low. Under these circumstances, when the sun's rays are withdrawn from the tree in late afternoon the temperature of the warmed area of the bark will fall rapidly to that of the atmosphere. As injury is greater when the temperature fall is rapid, especially in the first part of the freezing period, it is conceivable that the temperature of the tree may fall during the night to a point low enough to kill the tissue on the southwest side of the trunk, while that on the northeast side, protected by a slower temperature fall, will remain uninjured.

Other explanations are those offered by Burrill (page 242 of this bulletin); by Hartig (1900), who suggests that the bark becomes so warmed by the sun's rays in certain places that it expands considerably and separates from the wood; and by Sorauer (1909), who ascribes the phenomenon to tension differences in the tissues, set up by sudden temperature changes.

OBSERVATIONS AND EXPERIMENTS

Sun-scald injury may be considered a form of direct freezing to death caused in one of two ways: (1) an increased tenderness in the tissue on the sunny side of the trunk in late winter causes it to kill at a temperature not low enough to injure the still dormant tissue of the shaded side; or (2) the tissue on the sunny side kills at a higher temperature, due to the more rapid temperature fall that may take place after a cold, sunny day in late winter. It is of course possible that both these factors may be operative in causing the injury.

In order to test the relative value of these two hypotheses, some observations and experiments were made during the winters of 1913-14 and 1914-15. In the experiments reported below, the cambium was taken as the critical tissue, since in observed cases of sun-scald the cambium suffers severe injury, and without injury to the cambium and outermost xylem the bark would not separate from the wood nor would any injury beyond easy repair occur.

Temperatures that may occur in winter on the sun-exposed parts of the trunk

During the winters of 1913-14 and 1914-15, records were taken of the temperatures of the cortex and the outer sapwood on sun-exposed and shaded sides of the trunks of several apple trees, in order to ascertain just what temperature conditions may arise under given circumstances. The temperatures were taken with ordinary mercury thermometers of the chemical type. Since the result desired was a comparison of

temperatures, looking for fairly wide differences, no attempt was made to standardize these thermometers, but they were carefully compared before and after using and were found to check with one another within one-half of one degree. These thermometers were graduated in degrees Fahrenheit between −20° and +120°. In the following tables the readings have been transformed to the centigrade scale, which accounts for the decimal. No attempt was made to read the thermometers more closely than to one-half of a graduation interval.

The manner of insertion of the thermometers was as follows: A hole was bored tangentially into the tree trunk so that when the thermometer bulb was inserted it lay partly in the inner cortex and partly in the outer sapwood, while the stem projected horizontally or was slightly inclined upward. The hole was only very slightly larger than the diameter of the bulb, and after insertion of the thermometer the outer opening was sealed around the thermometer stem with paraffin. The thermometer bulb was thus entirely within the tissue, and it is not believed that the unavoidable small air space around the bulb introduced any material error into the observations.

Air temperatures were taken by means of a thermometer hung against the northeast side of the trunk just above the thermometer inserted on that side.

TABLE 1. TREE TEMPERATURES ON THE SOUTHWEST AND NORTHEAST SIDES UNDER CLOUDY CONDITIONS, 1914

Date	Hour*	Temperatures (degrees centigrade)		
		Southwest side	Northeast side	Air
Tree no. 3				
January 15	11.00	−6.9°	−7.8°	3.3°
16	1.30	−3.3°	−4.3°	2.2°
17	1.30	−1.9°	−3.0°	−3.0°
19	3.00	−3.3°	−3.3°	−2.2°
20	11.45	0.0	0.0	1.1°
21	1.00	−1.1°	−1.1°	−2.2°
23	1.10	−2.2°	−2.2°	0.0°
24	1.10	−0.5°	−0.5°	4.4°
Tree no. 38				
January 16	1.40	−3.3°	−3.3°	−2.2°
17	2.00	−1.8°	−3.3°	−4.4°
19	1.15	−3.3°	−3.3°	−2.2°
20	12.50	0.0	0.0	1.1°
21	1.30	−0.5°	0.0	3.3°
23	1.30	−0.5°	−1.8°	2.2°
24	1.30	0.0	−1.2°	4.4°

* Eastern time as in [illegible] for change with Mountain Time.

For the observations of 1913-14 two trees in the university orchards at Ithaca were selected. Tree no. 3 was a large old seedling tree with a trunk about three feet in diameter. Tree no. 38 was a twenty-years-old Baldwin tree with a trunk diameter of about ten inches. The thermometers were inserted about three feet from the ground in each case.

At the beginning of the observations, readings were taken on cloudy days as well as on sunny days, in order to determine whether any difference in temperature might occur due to any other influence than that of the sun. Some of these readings are given in table 1.

Temperatures that may be reached on a bright day by the tissue on the sun-exposed side of a tree are shown in table 2:

TABLE 2. TREE TEMPERATURES ON THE SOUTHWEST AND NORTHEAST SIDES ON SUNNY DAYS, 1914

Date		Tree no.	Hour*	Temperatures (degrees centigrade)		
				Southwest side*	Northeast side	Air
January	14	3	3.00	—2.8°	—12.2°	—12.2°
	26	3	2.25	1.1°	— 2.8°	— 1.4°
	26	38	3.10	—0.5°	— 2.5°	— 1.9°
February	2	3	1.30	12.2°	— 1.1°	— 0.5°
	2	38	2.00	7.7°	— 0.3°	0.0
	3	3	1.35	15.0°	2.8°	9.4°
	3	38	1.15	15.5°	0.0	5.0°
	4	3	1.05	12.8°	0.8°	1.6°
	4	38	1.30	11.7°	1.7°	2.2°
	8	3	2.10	—0.5°	— 4.4°	— 6.7°
	8	38	2.30	—1.7°	— 3.9°	— 6.1°
	9	3	12.50	—4.4°	— 9.4°	— 8.3°
	9	38	1.05	—5.6°	— 8.3°	— 8.3°
	13	3	1.00	—6.4°	—15.0°	—11.7°
	13	38	1.20	—1.1°	—10.0°	—12.2°
	15	3	2.50	3.9°	— 9.4°	—12.2°
	15	38	3.20	1.4°	— 8.3°	—12.2°
	23	3	1.00	—6.4°	—11.4°	—14.4°
	23	38	1.25	—4.4°	—11.4°	—16.1°
	24	3	1.00	—2.8°	—16.1°	.....
	24	38	1.20	—1.1°	—13.9°	—16.1°
	25	3	12.55	1.7°	— 9.7°	— 5.6°
	25	38	1.15	3.9°	— 2.8°	— 5.3°
	26	3	11.00	—1.9°	—10.0°	.....
March	10	3	1.30	20.5°	0.0	1.1°
	10	38	1.50	27.2°	2.2°	2.2°
	12	3	12.50	15.0°	— 3.3°	— 4.4°
	12	38	1.15	16.7°	0.0	— 4.4°
	24	3	1.15	12.2°	1.7°	3.9°
	24	38	1.35	11.1°	2.2°	2.2°
	25	3	1.00	11.1°	5.0°	8.9°
	25	38	1.25	10.6°	6.1°	7.8°

* Forenoon records are in light-faced type, afternoon records in black-faced type.

It is believed that in table 2 are found some of the highest temperatures reached in these particular trees during the three months of January, February, and March, 1914. It will be seen that the tissue on the southwest side of the tree is often much warmer than that on the northeast side. It does not, however, seem possible that these temperatures are high enough to start the tissue into activity. A significant fact is that on four days — January 14, and February 13, 15, and 24 — the tissue on the southwest side of the tree was nearly, if not quite, thawed out, while that on the northeast side was at a very low temperature. In this connection table 3 is of interest, showing temperatures in an old seedling tree, with a trunk diameter of about eighteen inches, at Clinton, New York, on January 1 and 2, 1914. The observations here recorded also give some idea of the possible rate of temperature fall on the southwest side when the sun leaves that part of the tree.

TABLE 3. TREE TEMPERATURES OBSERVED AT CLINTON, NEW YORK, AND AT ITHACA, NEW YORK, 1914

Date	Tree	Hour*	Temperatures (degrees centigrade)		
			Southwest side	Northeast side	Air
January 1.....	Old tree at Clinton	3.00	8.9°	—4.4°	—5.6°
		3.30	8.3°	—4.4°	—5.6°
		5.00†	0.0	—4.4°	—8.3°
January 2.....	Old tree at Clinton	11.00	7.2°	—8.3°	—10.9°
January 2.....	Tree no. 3 at Ithaca	3.00	—2.8°	—12.2°	—12.2°
		4.45‡	—7.8°	—15.0°	—15.6°
		5.15§	—9.4°	—15.3°	—16.1°

* Forenoon records are in light-faced type, afternoon records in black-faced type.
† A few minutes after sundown.
‡ Sun just down.
§ Thirty minutes after sundown.

Temperatures observed during the winter of 1914-15

Temperature observations were continued during the winter of 1914-15. Since it was believed that in the case of injury to the trees in the Everett orchard, mentioned on page 240, the indirect causal factor was the high temperature induced by the black color of the tarred trunk, some records were obtained from trees similarly blackened. Later in the winter records were taken from a whitewashed trunk, in order to learn whether a coating of whitewash would prevent an injurious rise in temperature. A space of about two feet up and down the trunk was tarred on November 23, 1914. The lower edge of this tarred space was two feet above the ground. The thermometers were inserted into the

middle of the tarred space. An additional thermometer was inserted six inches above the tarred space and on the southwest side of the tree. The whitewash was applied to a similar area on another tree. The whitewash gradually weathered off and was renewed once. Part of the time during which the records were taken the whitewash was in a somewhat washed-off condition. This was purposely allowed, in order to determine the effect of a poor coating of whitewash, since this would more nearly approximate conditions met with in the practical use of whitewash to prevent sun-scald.

Later in the winter thermometers were inserted into two small trees, whose trunk diameter was about three inches. In this case the whole of the thermometer bulb could not be as nearly contained in the cortex and outer sapwood as in the larger trees; the central part of the bulb was separated from the outer air by a layer of sapwood and bark about one-fourth inch thick. This would lead to error in the readings, but it may be assumed that the temperature of the cambial area would be if anything higher than the readings obtained.

The records for 1914-15 were taken at Ithaca from the following trees:

(a) Tree no. 6 — an old seedling tree in the Blair orchard, with a trunk diameter of about three feet. A part of the trunk was tarred and thermometers were placed in the tarred space on the southwest and northeast sides of the trunk, with a third thermometer six inches above the upper limit of the tarred space on the southwest side.

(b) Tree no. 3 — an old seedling tree in the Blair orchard, from which records were taken in 1914. Thermometers were placed on the southwest and northeast sides of the trunk, about three feet from the ground.

(c) Tree no. 0 — an old seedling tree in the Blair orchard, with a trunk diameter of about two and one-half feet. A space on the trunk was whitewashed, and thermometers were placed in the center of the whitewashed area on the southwest and northeast sides and about three feet from the ground.

(d) Tree no. 24 — of the variety Gano, in the university orchard, with a trunk diameter of three inches. On January 30 thermometers were placed on the southwest and northeast sides about three feet from the ground.

(e) Tree no. 25 — a similar tree to no. 24. Thermometers were placed on the southwest side of the trunk in the center of a tarred space.

The air temperatures were taken by means of maximum and minimum thermometers, one hung on the northeast side of the trunk of tree no. 6 in the Blair orchard, the other on the northeast side of a large post near trees no. 24 and no. 25 in the university orchard.

The records obtained during the winter of 1914-15 are given in table 4. The readings were all taken on bright days.

TABLE 4. TEMPERATURES (IN DEGREES CENTIGRADE) OBSERVED ON DIFFERENT SIDES OF TREES TREATED WITH TAR AND WITH WHITEWASH, AND OF UNTREATED TREES, DURING THE WINTER OF 1914–15

Date	Blair orchard									University orchard					Notes
			Tree no. 6			Tree no. 3		Tree no. 0				Tree no. 24		Tree no. 25	
	Hour of reading*	Air temperature	North-east side. Tarred space	South-west side. Above tarred space	South-west side. Tarred space	North-east side	South-west side	North-east side. Whitewashed	South-west side. Whitewashed	Hour of reading*	Air temperature	North-east side	South-west side	South-west side. Tarred	
December 15	7.00	—17.2°	—13.9°	—12.2°	—13.9°	—13.9°	—13.9°	.....	.....	.....	.....	.....	.....	.....	Minimum for night, —20°
15	1.45	—10.0°	— 5.0°	— 0.9°	— 0.9°	— 7.2°	— 3.1°	.....	.....	.....	.....	.....	.....	.....	
16	1.45	— 6.1°	— 5.0°	— 0.3°	4.1°	— 6.7°	— 1.1°	.....	.....	.....	.....	.....	.....	.....	
17	9.00	—15.0°	—11.1°	—10.0°	—10.6°	—12.2°	—11.1°	.....	.....	.....	.....	.....	.....	.....	Minimum for night, —16.1°
17	1.30	— 5.6°	— 4.4°	2.2°	7.8°	— 6.7°	1.1°	.....	.....	.....	.....	.....	.....	.....	
18	1.30	— 6.1°	— 5.3°	0.6°	4.2°	— 7.2°	— 1.1°	.....	.....	.....	.....	.....	.....	.....	
19	7.30	— 3.9°	— 5.3°	— 4.4°	— 4.4°	— 5.9°	— 5.3°	.....	.....	.....	.....	.....	.....	.....	Minimum for night, —11.1°. Grew warmer in night
January 5	1.15	1.1°	— 0.9°	5.6°	10.0°	— 1.9°	4.4°	.....	.....	.....	.....	.....	.....	.....	
7	1.15	4.4°	4.4°	8.9°	11.9°	.....	6.9°	.....	.....	.....	.....	.....	.....	.....	
15	1.00	3.9°	3.3°	16.1°	20.5°	1.7°	11.1°	0.6°	2.2°	.....	.....	.....	.....	.....	
22	1.00	— 7.2°	— 6.1°	2.5°	6.7°	.....	2.2°	— 6.1°	— 3.9°	.....	.....	.....	.....	.....	
26	1.00	— 0.6°	— 1.1°	12.8°	21.1°	.....	11.1°	— 4.4°	0.0	.....	.....	.....	.....	.....	
29	1.40	— 7.2°	— 3.9°	— 1.7°	1.7°	.....	— 3.3°	— 7.2°	— 5.3°	.....	.....	.....	.....	.....	
30	8.30	—13.9°	—12.8°	—12.8°	—12.8°	—13.9°	—12.8°	—13.3°	—13.3°	.....	.....	.....	.....	.....	Minimum for night —17.2°
30	1.40	— 5.6°	— 4.7°	5.3°	12.2°	— 8.3°	2.2°	— 8.9°	— 3.9°	2.00	— 5.6°	—2.2°	— 3.3°	.....	
30	2.20	— 5.6°	— 4.9°	6.7°	13.9°	— 8.3°	4.4°	— 8.9°	— 2.8°	2.30	— 5.6°	—2.2°	4.4°	.....	
30	2.40	— 6.7°	— 4.9°	6.7°	14.2°	— 7.8°	4.7°	— 8.6°	— 2.2°	.....	.....	.....	.....	.....	
30	3.40	— 7.8°	— 5.6°	2.8°	7.2°	— 8.3°	2.2°	— 8.9°	— 2.5°	.....	.....	.....	.....	.....	
February 4	2.45	0.0	— 0.6°	9.4°	17.8°	— 3.3°	7.2°	— 4.1°	1.1°	2.55	0.0	— 0.3°	13.3°	17.8°	
4	4.35	— 4.4°	— 2.2°	2.8°	5.6°	— 3.9°	1.7°	— 4.4°	— 0.6°	4.45	— 4.4°	0.0	7.2°	9.4°	
10	7.15	—11.7°	—10.0°	— 8.9°	— 9.4°	—10.6°	— 9.4°	—10.0°	—10.0°	7.25	—11.7°	—11.7°	—11.7°	—11.7°	Minimum for night, —12.2°
10	2.00	— 1.7°	— 1.1°	18.0°	29.0°	— 3.9°	15.0°	— 6.7°	— 0.6°	2.15	— 1.7°	— 0.9°	19.7°	26.6°	
10	9.00	— 7.2°	— 6.1°	— 2.2°	— 2.8°	— 7.2°	— 2.8°	— 7.2°	— 6.1°	9.10	— 8.0°	— 6.7°	— 6.9°	— 7.8°	
19	2.15	3.9°	0.0	22.2°	31.1°	— 1.7°	17.2°	— 2.2°	5.0°	.....	.....	.....	.....	.....	
20	2.05	6.1°	1.7°	25.0°	33.3°	0.0	21.7°	— 0.6°	6.1°	2.20	.....	11.1°	21.7°	25.0°	
March 8	4.45	— 1.7°	1.1°	12.2°	17.8°	.....	9.4°	— 1.7°	6.4°	4.45	— 3.3°	1.7°	11.7°	.....	

* Forenoon records are in light-faced type, afternoon records in black-faced type.

Some additional facts may be gained from a study of table 4. The black color of the tarred surface where exposed to the sun seems to be very effective in raising the temperature of the inner bark and the outer sapwood much above that of the air, and also considerably above that of the similarly sun-exposed but untarred surface. Conduction from this warmed area was sufficient to warm the tissue six inches above the upper limit of the tar to a temperature higher than that of the untarred, sun-exposed trunk. Probably this conduction is also felt in the direction of the circumference, since the temperatures on the northeast side of the blackened tree were slightly higher than appears normal for the shaded side. This would no doubt have been more noticeable with a smaller tree, but unfortunately this point was not ascertained. On the other hand, the coating of whitewash, even when considerably weathered (as shown by readings subsequent to February 10), seemed effective in preventing a considerable rise in temperature on the sun-exposed side of the trunk.

The temperature of the shaded side of the trunk is very rarely exactly the same as the temperature of the air at the time of the reading, but is slightly lower if the temperature of the air is and has been rising, and higher if the air temperature has been falling. This is what naturally would be expected — that the tree temperature would follow the air temperature rather closely, but would not undergo as rapid changes.

The early morning readings deserve consideration. On December 14, the air temperature fell rapidly during the afternoon and reached a minimum of −20° C. sometime in the night. At seven o'clock in the morning on December 15, the air temperature had risen but slightly above the minimum, namely, to −17.2°. The lowest tree temperature at this hour was −13.9°. It appears that the tree temperature had not kept pace with the rapid temperature fall of the atmosphere, and that −13.9° was the minimum reached by the tree during that night. Subsequent observations on other days, made in the morning before the air had warmed much above the minimum for the night, confirm this point. On December 17, the minimum for the previous night was −16.1°; at nine o'clock in the morning the air temperature was −15°; the lowest tree temperature was −12.2° (on the northeast side of tree no. 3), and the highest was −10° (on the southwest side of tree no. 6). On December 19, the lowest atmospheric temperature for the previous night was −11.1°, reached at ten o'clock; about midnight the atmospheric temperature began to rise, and at half past seven had reached −3.9°; the tree temperatures at that hour were fairly close to the air temperature. On January 30, the minimum for the previous night was −17.2°; at half past eight in the morning the air temperature had risen to −13.9°, but the tree temperatures were yet considerably above the minimum

for the night, the lowest tree temperature being −13.9° and the highest −12.8°.

Probably the explanation of this phenomenon lies in the fact that the large trunk contains a considerable quantity of stored heat, which operates to prevent a rapid temperature fall in the tree tissue. In the case of the temperatures discussed above, the trees were all large and old, with thick bark and great diameter of trunk. It was thought probable that a tree with a trunk diameter of only three or four inches would follow the changes in atmospheric temperature much more closely. This seems to be true. On February 10, the minimum air temperature for the previous night was −12.2°. At a quarter past seven in the morning the air temperature was −11.7°; the lowest tree temperature in the old trees was −10.6°, and the highest −8.9°, on the southwest side of the trunk; the thermometers in the young trees all stood at −11.7°, the then air temperature. It is not improbable that the young trees had reached the air minimum and again warmed up, following the air temperature closely. Another observation on this point was taken at nine o'clock in the evening on February 10. An examination of the records for that hour, together with those for two o'clock on the same afternoon, indicates that the younger trees, with smaller trunk diameter, follow the atmospheric temperature fall more closely than do the large old trees. In this connection it is interesting to recall that trees with a trunk diameter of less than a foot are more subject to sun-scald than are larger trees. Rarely, if ever, does sun-scald occur on large old trees. As will be seen later, in artificial freezings tissue from old trees does not seem particularly hardy as compared with that from young trees.

It will also be noticed that temperatures on the southwest side of the trunk were somewhat higher in the young trees than in the old ones. This was perhaps due to the difference in bark color and thickness; the bark on the old trees was thick and light gray, while that on the young trees was thinner and of a reddish brown color.

In young trees the temperature on the northeast side of the trunk rises above the air temperature on sunny days, tho not so high as that on the southwest side. This is not true in the case of old trees. The difference is probably due to the greater ease of conduction thru and around the smaller trunk.

These differences in behavior of large and small tree trunks are even more evident in table 5, which records temperatures observed at Geneva, New York, February 14, 1916. The trees compared were a large old Baldwin, and a young Century whose trunk diameter was about four inches. Especially remarkable is the rapidity of temperature fall in the small trunk after sundown.

TABLE 5. COMPARATIVE TEMPERATURE RECORDS FROM LARGE AND SMALL TREES, FEBRUARY 14, 1916

Hour of reading (p. m.)	Temperature (degrees centigrade)			
	Small tree, northeast side	Small tree, southwest side	Large tree, southwest side	Air
2.00	— 3.3°	1.1°	.....	11.1°
3.00	— 5.0°	5.5°	.....	12.5°
4.00	— 7.2°	3.9°	.....	—13.5°
5.00*	— 9.4°	— 0.3°	3.9°	—14.4°
6.00†	—18.3°	—14.4°	—3.3°	—22.2°

* Thirty minutes before sundown.
† Thirty minutes after sundown.

One fact which cannot be readily explained is that the temperature on the northeast side of tree no. 3, both in 1914 and in 1915, was often slightly lower than that of the air. It was thought that possibly some error had been made in the original comparison of thermometers; but the thermometer in this place was twice broken and replaced, and it does not seem probable that the same error would occur three times in standardizing.

Some of the more striking records from tables 2, 3, and 4 are grouped together in table 6. The readings are expressed in degrees Fahrenheit, since the Fahrenheit scale is the one commonly employed in reporting atmospheric temperatures.

A comparison of the date of awakening and relative hardiness of the cambial area on the northeast and southwest sides of the trunk

Müller-Thurgau, as has already been stated, suggests that the occurrence of sun-scald may be due to an early awakening, and consequent increased tenderness, of the tissue on the southwest side of the tree, brought about by the action of the sun in late winter. The temperature records obtained do not offer much support for this hypothesis, but it was considered worth while to obtain some evidence for or against it.

Cuttings, including bark, cambium, and outer sapwood, were taken in 1914 from a large old seedling tree (no. 5) in the Blair orchard, and from a young Northern Spy tree (no. 17) in the university orchard whose trunk diameter was about three inches. The cuttings were taken from approximately the same height on the southwest and northeast sides of the trunk, on the following dates: January 20, March 16, April 8, May 2, May 16, and May 31. They were fixed, infiltrated, and imbedded in collodion, and sections were made and examined microscopically for signs of cambial activity.

TABLE 6. STRIKING DIFFERENCES IN TEMPERATURES ON SUN-EXPOSED AND SHADED SIDES OF TREES

Date	Temperatures (degrees Fahrenheit)									
	Air	Large tree		Large tree, tarred		Large tree, whitened		Air	Medium-sized tree	
		Northeast side	Southwest side	Northeast side	Southwest side	Northeast side	Southwest side		Northeast side	Southwest side
(1914)										
January 2...	10°	10°	27°	.....	.....	.....	.....	.....	.....	.....
January 13...	11°	5°	20.5°	.....	.....	.....	.....	10°	14°	30°
February 15...	10°	15°	39°	.....	.....	.....	.....	10°	17°	34.5°
February 24...	.....	3°	27°	.....	.....	.....	.....	3°	7°	30°
December 15...	14°	19°	26.5°	23°	30.5°	.....	.....	.....	.....	.....
									Small tree	
									Northeast side	Southwest side
(1915)										
January 22...	19°	.....	36°	21°	44°	21°	25°	.....	.....	.....
January 30...	20°	18°	40.5°	23°	57.5°	16.5°	28°	22°	28°	40°
February 20...	43°	32°	71°	35°	92°	31°	43°	43°	52°	71°

The cambium appeared in its winter condition in all sets of cuttings up to those taken on May 2. In the cuttings taken on this date the cambium appeared to be beginning activity and a few recently formed tracheal elements and xylem cells were in evidence. There was no discernible difference on this date in the condition of the cuttings from the opposite sides of the trunk. If the cambium on the southwest side started into activity before that on the northeast side, this must have occurred sometime between April 8 and May 2. In this latitude, temperatures sufficiently low to cause injury to the awakening cambium could hardly be expected to occur so late in the spring as this. On May 31 considerable new xylem had been laid down inside the now thoroly active cambial ring. Again no difference could be detected between cuttings from the southwest and the northeast side of the trunk.

In 1915, cuttings that were taken for artificial freezing from several trees as late as April 13 were incidentally examined for signs of cambial awakening, but no such signs were observed on that date. The next opportunity for observation on this point was at Peru, Clinton County, on May 1. At that date growth had begun on both sides of the trunk. The season at Ithaca is a few days in advance of the season at Peru, so that observations made in the two places are fairly comparable. Brown (1912), in studies on growth in *Pinus rigida* Mill., found no difference in the time of cambial awakening on the north and south sides of the trunk.

Since there is doubtless some not thoroly understood change that takes place in the protoplasm before growth begins, it was believed that an increased tenderness in the cambium might easily be observed before growth itself, and that this would be a more accurate test of Müller-Thurgau's hypothesis. Any increased tenderness in the cambium could by careful manipulation be detected by artificial freezing.

At different times in 1914 and 1915, tissue from various old and young trees was subjected to artificial freezing in order to determine this point. Cuttings were taken from the southwest and northeast sides at the same height on the trunk — from two and one-half to three feet from the ground. Each cutting included bark, cambium, and a thin layer of sapwood, and was removed with extreme care so as to avoid mechanical injury to the tissues, which might introduce error into the results. The cuttings were shaved down as nearly as possible to the same thickness (from two to two and one-half millimeters) and cut into pieces of the same area, three pieces being made from each cutting. The pieces prepared in 1914 were about six millimeters square; those prepared in 1915 were punched out with a cork borer the diameter of which was six millimeters. Each piece thus represented a small area of the cambium,

with equal thicknesses of cortex and xylem on either side. The pieces were made small in order that temperature changes in them could take place evenly and rapidly; it was believed that with pieces of this size close to or in contact with the thermometer bulb, the thermometer reading would be a fairly accurate representation of the internal temperature.

In the experiments conducted in 1914 the pieces were firmly tied with fine thread to the thermometer bulb, one on each side. The thermometer was inserted thru a cotton plug into a test tube in such a manner that the lower end of the bulb just cleared the bottom of the test tube. For the first part of the freezing process the tube was inserted into a larger tube, similarly plugged in order to secure insulation by the dead-air space between the two tubes. The larger tube was then placed in an earthen vessel containing, first ice, then ice and salt. The proportion of salt in the freezing mixture was gradually increased each time the mixture was replaced. When a certain minimum temperature was reached, the larger outer tube was removed and the inner tube placed directly in the freezing mixture. By means of these precautions it was possible to regulate the temperature fall so that it was even and slow. This was extremely desirable, since, as Chandler (1913) has shown, a rapid temperature fall, especially in the first part of the freezing, is markedly injurious. As the object sought was to determine any difference in hardiness between the two samples of tissue, a too rapid rate of temperature fall might be a source of too great error.

In these experiments it usually took from six and one-half to seven hours to reach the minimum temperature obtainable with salt and ice. The tube was then removed, and placed in an insulated vessel containing a mixture of crystallized calcium chlorid and ice (the ice and calcium chlorid having been previously cooled to the temperature of salt and ice). The proportions of this mixture were also varied, but it was not possible to prevent a fairly rapid temperature fall at this stage of the freezing. Since, however, it is in the early part of the freezing that the effect of rapidity of fall is most noticeable, this was not regarded as a great source of error. The temperature was read and recorded every fifteen minutes up to the time of the employment of calcium chlorid, and from then on every five minutes. The thermometers used in 1914 were mercury thermometers similar to those employed in taking tree temperatures. These were later compared with the standardized thermometers used in 1915. The thermometers used in 1915 were two spirit thermometers graduated in degrees centigrade from $-50°$ to $+80°$. These were standardized by the United States Bureau of Standards.

The apparatus used for the freezing work in 1915 is shown in figure 61. Essentially it consisted of three concentric tin cylinders, of which the innermost one constituted a chamber for the material to be frozen, and the outer two were containers for the freezing mixture. These three cylinders were inclosed on sides and bottom in an outer chamber filled with insulating material. A shaft passing down into the central cylinder bore near its lower end a small tin disk, on the upper surface of which were a number of small pin points. The material to be frozen was placed on these points. The disk was made to revolve slowly during the freezing process, by means of a pulley of large circumference attached to the upper end of the shaft and driven by a belt from a small, low-speed electric motor. This was in order to make sure that the various pieces of tissue would be subjected to the same temperatures and to the same rate of temperature fall, since all parts of the central cylinder might not be at exactly the same temperature.

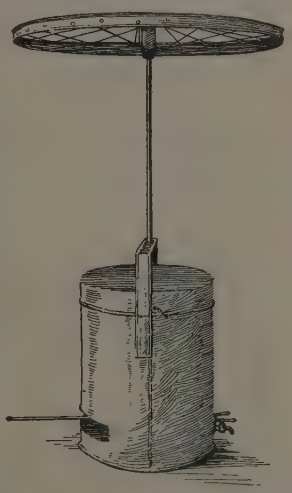


FIG. 61. FREEZING MACHINE USED FOR ARTIFICIAL FREEZING EXPERIMENTS

A recess was cut into the lower part of the apparatus at one side, as far as the wall of the central cylinder, allowing a thermometer to be inserted thru a cork in such a manner that the bulb was wholly within the central cylinder and just beneath the revolving disk, while the stem was wholly in the outer air. By means of this arrangement the temperature could be read whenever desired without disturbing either thermometer or tissue. The apparatus was made rather deep in order to allow room for insulation of wool felt which was packed in the upper parts while the freezing was going on. The whole apparatus was covered by an easily removable lid. The freezing-mixture chambers were provided with drainpipes and stopcocks.

In the freezing process the outer cylinder was filled with ice-and-salt mixtures, with gradually increasing proportions of salt, until the minimum temperature that could be obtained with this mixture was reached, the dead-air space of the second cylinder meanwhile acting as insulation to prevent too rapid temperature fall. A calcium-chlorid-and-ice mixture was then placed in the second cylinder until the desired temperature was reached.

One defect was observed with this machine when low temperatures were desired. As is well known, a mixture of calcium chlorid and ice

is not particularly efficient as compared with salt and ice. In this apparatus its efficiency was still further impaired by the heat lost in freezing the water that was unavoidably present in the ice-and-salt mixture of the outer chamber.[5] In the later freezings of 1915, when a temperature below −28° C. was desired it was necessary to place the tissue in thin-walled glass shells attached to the shaft near its lower end, and when the minimum of the machine was reached to remove these quickly and place them in a calcium-chlorid-and-ice mixture contained in an insulated vessel. In this case the thermometer bulb was placed directly in the mixture. Several vessels were employed, each with a mixture whose temperature was slightly lower than the preceding, so that the temperature fall could be regulated to comparative slowness.

The temperatures were read and recorded at the same intervals as in the 1914 experiments, and the same rate of temperature fall was maintained.

Before each set of freezings, preliminary freezings were run with tissue from the north or the east side of the trunk until the killing point of the cambium was determined; then the tissue to be compared was carried down to that point — or usually to a degree or two short of that point, as any differences in hardiness could more readily be noted if the killing was partial. Indeed, when, as was often the case, there was almost no injury and it was at the same time known that the killing point had been all but reached, the results were considered as valuable as when there was more evident injury; since if the insolated tissue were noticeably tenderer, it would certainly kill under such conditions.

The amount of injury was determined by examination under the low power of the microscope. The edges of the pieces were trimmed and free-hand sections were cut across the center of the pieces in every case, as occasionally unavoidable mechanical injury to the outer edge of a piece would increase the amount of killing in that region.

As is well known, the anatomical cambium consists of several layers of cells, of which properly only the central layer is the true, or physiological, cambium. In these freezing experiments the tissue first injured was the layer of cambial cells next to the last-formed layer of xylem cells, in other words, the youngest wood elements. Occasionally the interfascicular cambium seemed to be the tenderest tissue. Since severer injury was marked by extension of the discolored line to include more layers of the anatomical cambium until complete killing showed them all discolored, the amount of injury could be readily estimated in percentage and in many cases is so expressed in the tabulated results.

[5] This defect in the apparatus could be remedied easily by constructing the outer freezing chamber with false walls so that the ice-and-salt mixture could be removed and the space filled with wool-felt insulation. With this improvement it is believed that the machine would be efficient to as low temperatures as are ever desired.

Before examination the pieces were left for from twenty-four to forty-eight hours after the freezing, when the characteristic brown discoloration of cell contents caused by frost injury could be recognized readily. Several unfrozen pieces of tissue were similarly left and examined each time, but in no case was the discoloration present in them. Of course the time when such freezings should be run in order to determine the point in question is late winter and early spring; but in order to throw light on the general question of hardiness, freezings were run at intervals thruout the entire dormant period, and the results are thought to be of sufficient interest to be reported here. They are given in table 7:

TABLE 7. RECORD OF ARTIFICIAL FREEZING EXPERIMENTS TO DETERMINE RELATIVE HARDINESS OF TISSUE OF THE TRUNKS OF TREES IN 1914-15

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
1	(1914) Jan. 28	Northeast side, 20-years-old Baldwin tree no. 38	3½	—20.6°	30	Evident injury to cambium, slight injury to cortex, no injury to xylem
		Southwest side, same tree				Injury not noticeably different
2	Jan. 30	Northeast side, old seedling tree no. 7	7	—20.0°	30	Slight injury to cambium
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 3	7	—20.6°	30	Very slight injury to cambium
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 17	7	—21.0°	30	No injury
		Southwest side, same tree				No injury
3	Feb. 2	Northeast side, old seedling tree no. 7	7	—20.6°	45	No injury
		Southwest side, same tree				No injury
		Northeast side, old seedling tree no. 6				No injury
		Southwest side, same tree				No injury
4	Feb. 21	Northeast side, old seedling tree no. 4	6½	—22.2°	Warmed immediately	Slight injury to cambium and cortex, very slight injury to xylem
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 7				Same
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 18				Injury as above, but less injury to cambium
		Southwest side, same tree				Same
5	Feb. 27	Northeast side, old Bellflower tree no. 9	7½	—20.0°	30	Severe injury to cambium, slight to medullary rays of cortex
		Southwest side, same tree				Almost no injury
		Northeast side, young Gano tree no. 20				Very slight injury to cambium

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1914)					
5	Feb. 27	Southwest side, same tree	7¼	—20.0°	30	Same
		Northeast side, young Gano tree no. 21				Same
		Southwest side, same tree				No injury
		Northeast side, young Northern Spy tree no. 22				No injury
		North side, old Bellflower tree no. 9				No injury
		North side, tree no. 22	½	—20.0°	30	No injury
		North side, tree no. 9				No injury
6	Mar. 19	Northeast side, old tree, variety unknown, no. 39	7	—28.0°	60	Complete injury to cambium, severe to cortex, slight to xylem
		Southwest side, same tree				Same
		Northeast side, old tree, variety unknown, no. 40				Same as above, but slightly less injury to cambium
		Southwest side, same tree				Same
		Northeast side, old tree, variety unknown, no. 41				Complete injury to cambium, severe to cortex, slight to xylem
		Southwest side, same tree				Same
		North side, old tree no. 41	2½	—18.3°	30	Severe injury, not noticeably different from that of slowly frozen tissue
		North side, old tree no. 41				
		North side, old tree no. 40				
7	Mar. 28	Northeast side, old seedling tree no. 8	6	—26.1°	45	Slight injury to interfascicular cambium and medullary rays
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 11				No injury
		Southwest side, same tree				No injury
		Northeast side, old seedling tree no. 5				No injury
		Southwest side, same tree				No injury
		Northeast side, old seedling tree no. 13				Slight injury to interfascicular cambium and medullary rays, slight injury to outer xylem next to cambium
		Southwest side, same tree				Slight injury to interfascicular cambium and medullary rays
8	Nov. 11	Six pieces from old tree no. 39	6	—11.1°	60	No injury
9	Nov. 14	Old seedling tree no. 1	10	—21.1°	30	Injury severe to xylem, less severe to cortex. No injury to cambium
10	Nov. 16	Old seedling tree no. 1, crown, 4 inches above soil	6¼	—21.7°	5	95 per cent* injury to cambium, very little to cortex or xylem

* Estimate from microscopic examination.

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1914)					
10	Nov. 16	Same tree, trunk, 2½ feet up	6¾	—21.7°	5	Very slight injury to cambium, slight to cortex and xylem
		Same tree, crown, 4 inches above soil	7	—23.9°	30	All cambium injured
		Same tree, trunk, 2½ feet up				75 per cent injury to cambium
11	Nov. 21	Northeast side, old seedling tree no. 2	8	—21.2°	30	15 per cent injury to cambium
		Southwest side, same tree				10 per cent injury to cambium, considerable to cortex and xylem
		Northeast side, old seedling tree no. 4, trunk tarred Oct. 23				No injury to cambium
		Southwest side, same tree				No injury to cambium
		Northeast side, old seedling tree no. 8, trunk tarred Oct. 23				Very slight injury to cambium, considerable to cortex, less to xylem
		Southwest side, same tree				Very slight injury to cambium (one piece showed about 10 per cent)
		Northeast side, old seedling tree no. 11				Very slight injury to cambium (less than 1 per cent)
		Southwest side, same tree				No injury to cambium
		Northeast side, young Gano tree no. 15				No injury to cambium
		Southwest side, same tree				No injury to cambium
		Northeast side, young Gano tree no. 16, trunk tarred Oct. 23				No injury to cambium
		Southwest side, same tree				No injury to cambium
12	Nov. 23	Northeast side, young Northern Spy tree no. 18, trunk tarred Oct. 23	7⅛	—23.3°	55	50 per cent injury to cambium
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 17				45 per cent injury to cambium
		Southwest side, same tree				15 per cent injury to cambium
		Northeast side, young Gano tree no. 20				No injury to cambium (except very slight injury to one piece)
		Southwest side, same tree				No injury to cambium
		Northeast side, young Gano tree no. 23, trunk tarred Oct. 23				60 per cent injury to cambium
		Southwest side, same tree				20 per cent injury to cambium
		Young Northern Spy tree no. 22, head, 2½ feet above soil				No injury to cambium
		Same tree, crown, 4 inches above soil				No injury to cambium
13	Dec. 14	West side, old seedling tree no. 1, 4 feet above soil	7½	—25.0°	30	Very slight injury to cambium, cortex, and xylem

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1914)					
13	Dec. 14	West side, same tree, 2 feet above soil	7½	—25.0°	30	25 per cent injury to cambium, slight to cortex and xylem
		West side, same tree, 4 inches above soil				30 per cent injury to cambium, slight to cortex and xylem
14	Dec. 17	Northeast side, old seedling tree no. 2	Material in freezer placed outside at 6 p. m. Dec. 17. At 9 a.m. Dec. 18, temperature in freezer was —12° C. Freezing continued by means of calcium chlorid and ice 1 hr. 50 min. to —25.5° C.	.....	60	5 per cent injury to cambium, slight to cortex and xylem, especially to medullary rays
		Southwest side, same tree				10 per cent injury to cambium, considerable to cortex and xylem, especially to medullary rays
		Northeast side, old seedling tree no. 4, trunk tarred				15 per cent injury to cambium, especially to interfascicular cambium, slight to cortex and xylem
		Southwest side, same tree				10 per cent injury to cambium, especially to interfascicular cambium, slight to cortex and xylem
		Northeast side, old seedling tree no. 8, trunk tarred				10 per cent injury to cambium, slight to cortex, considerable to xylem
		Southwest side, same tree				20 per cent injury to cambium, considerable to cortex and xylem
		Northeast side, old seedling tree no. 11				25 per cent injury to cambium, considerable to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 15				35 per cent injury to cambium, especially to interfascicular cambium, considerable to cortex and xylem, especially medullary rays
		Southwest side, same tree				30 per cent injury to cambium, considerable to cortex and xylem, especially medullary rays
		Northeast side, young Gano tree no. 16, trunk tarred				10 per cent injury to cambium and interfascicular cambium, slight to cortex and xylem
		Southwest side, same tree				15 per cent injury to cambium and interfascicular cambium, slight to cortex and xylem*

*Note: Xylem injury unless otherwise noted was to xylem cells.

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1914)					
15	Dec. 18	Northeast side, young Northern Spy tree no. 18, trunk tarred	7½	—23.0°	40	70 per cent injury to cambium, severe to cortex, slight to xylem
		Southwest side, same tree				60 per cent injury to cambium, severe to cortex, slight to xylem
		Northeast side, young Northern Spy tree no. 17				25 per cent injury to cambium, severe to cortex, slight to xylem
		Southwest side, same tree				20 per cent injury to cambium, severe to cortex, slight to xylem
		Northeast side, young Gano tree no. 20				50 per cent injury to cambium, severe to cortex, slight to xylem
		Southwest side, same tree				35 per cent injury to cambium, slight to cortex and xylem
		Northeast side, young Gano tree no. 23, trunk tarred				75 per cent injury to cambium, severe to cortex, considerable to xylem
		Southwest side, same tree				80 per cent injury to cambium, considerable to cortex, slight to xylem
		East side, young Northern Spy tree no. 22, 3 feet above soil				80 per cent injury to cambium, severe to cortex, very slight to xylem
		East side, trunk, same tree, 1½ feet above soil				Same
		East side, crown, same tree, 4 inches above soil				65 per cent injury to cambium, severe to cortex, very slight to xylem
Note: Xylem injury in this case was confined to medullary rays, no wood cells injured.						
	(1915)					
16	Jan. 13	Old seedling tree no. 1, 4 feet above soil	6⅝	—23.0°	30	Very slight injury to cambium, cortex, and xylem
		Same tree, 2 feet above soil				Same
		Same tree, 6 inches above soil				Very slight injury (about 1 per cent) to cambium, slight to cortex and xylem
		Old seedling tree no. 7, 4 feet above soil				No injury to cambium, slight to cortex and xylem
		Same tree, 6 inches above soil				Very slight injury to cambium, cortex, and xylem
		Old Bellflower tree no. 9, 4 feet above soil				Very slight injury to cambium, slight to cortex, very slight to xylem
		Same tree, 2 feet above soil				Very slight injury to cambium, slight to cortex and xylem (one piece showed 100 per cent cambium injury and severe cortex injury)
		Same tree, 6 inches above soil				Very slight injury (about 1 per cent) to cambium, slight to cortex and xylem

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1915)					
17	Jan. 16	Old seedling tree no. 1, 4 feet above soil	6½	—26.0°	90	About 2 per cent injury to cambium, slight injury to cortex and xylem
		Same tree, 6 inches above soil				From 1 to 2 per cent injury to cambium, very slight to cortex and xylem
		Old Bellflower tree no. 9, 4 feet above soil				Very slight injury to cambium, cortex, and xylem
		Same tree, 2 feet above soil				Very slight injury (less than 1 per cent) to cambium, very slight to cortex and xylem
		Same tree, 6 inches above soil				From 1 to 2 per cent injury to cambium, very slight to cortex and xylem
		Old seedling tree no. 12, 4 feet above soil				From 2 to 5 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 6 inches above soil				10 per cent injury to cambium, very slight to cortex and xylem
	Note: Xylem slightly more injured than cortex.					
18	Jan. 20	Northeast side, old seedling tree no. 2	6	—26.5°	30	Very slight injury to cambium, considerable to cortex, slight to xylem
		Southwest side, same tree				Very slight injury to cambium, slight to cortex and xylem
		Northeast side, old seedling tree no. 8, trunk tarred				Very slight injury to cambium, considerable to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 11				Very slight injury to cambium, slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, considerable to cortex and xylem
		Northeast side, young Gano tree no. 15				Very slight injury to cambium, slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, slight to cortex and xylem
		Northeast side, young Gano tree no. 16				Very slight injury to cambium, slight to cortex and xylem
		Southwest side, same tree				Same
19	Jan. 23	Northeast side, young Northern Spy tree no. 18	7½	—33.0°	40	Very slight injury to cambium, about 5 per cent to interfascicular cambium, slight to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 17				Very slight injury to cambium, mostly to interfascicular cambium, slight to cortex and xylem

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1915)					
19	Jan. 23	Southwest side, same tree	7 5/12	—33.0°	40	Very slight injury to cambium, about 5 per cent to interfascicular cambium, slight to cortex and xylem
		Northeast side, young Gano tree no. 20				From 1 to 5 per cent injury to cambium, considerable to xylem, less to cortex
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 23, trunk tarred				Very slight injury to cambium, about 5 per cent to interfascicular cambium, slight to cortex and xylem
		Southwest side, same tree				Very slight injury to cambium, considerable to xylem, less to cortex
		Young Northern Spy tree no. 22, trunk, 1½ feet above soil				Very slight injury to cambium, about 10 per cent to interfascicular cambium, considerable to xylem, slight to cortex
		Same tree, head, 3 feet above soil				Same
		Same tree, crown, 4 inches above soil				Very slight injury to cambium, about 5 per cent to interfascicular cambium, slight to cortex and xylem
20	Jan. 27	Young Northern Spy tree no. 35, 2 feet above soil	6½	—38.0°	40	95 per cent injury to cambium, severe to cortex, less to xylem
		Same tree, 1 inch above soil				From 85 to 90 per cent injury to cambium, severe to cortex and xylem
		Young Northern Spy tree no. 42, head, 3 feet above soil				95 per cent injury to cambium, severe to cortex and xylem
		Same tree, 2 feet above soil				From 95 to 100 per cent injury to cambium, severe to cortex and xylem
		Same tree, 1 inch above soil				95 per cent injury to cambium, severe to cortex and xylem
		Young Northern Spy tree no. 34, at head in crotch				Complete injury to cambium, severe to cortex and xylem
		Same tree, 2 feet above soil				Same
		Same tree, 1 inch above soil				Same
		Young Northern Spy tree no. 30, 2 feet above soil				From 90 to 95 per cent injury to cambium, severe to cortex and xylem
		Same tree, 1 inch above soil				90 per cent injury to cambium, severe to cortex and xylem
Note: Injury greater in extent in cortex than in xylem.						
21	Feb. 22	Northeast side, old seedling tree no. 2	6	—38.0°	20	5 per cent injury to cambium, considerable to cortex and xylem

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1915)					
21	Feb. 22	Southwest side, same tree	6	—38.0°	20	10 per cent injury to cambium, considerable to cortex and xylem
		Northeast side, old seedling tree no. 4, trunk tarred				5 per cent injury to cambium, considerable to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 8, trunk tarred				Same
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 11				Same
		Southwest side, same tree				8 per cent injury to cambium, considerable to cortex and xylem
22	Feb. 24	Northeast side, young Gano tree no. 15	6	—37.0°	30	95 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				100 per cent injury to cambium, severe to cortex and xylem
		Northeast side, young Gano tree no. 16, trunk tarred				Same
		Southwest side, same tree				98 per cent injury to cambium, severe to cortex and xylem
		Northeast side, young Northern Spy tree no. 18, trunk tarred				Same
		Northeast side, young Northern Spy tree no. 17				100 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 20				97 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				100 per cent injury to cambium, severe to cortex and xylem
		Northeast side, young Gano tree no. 23, trunk tarred				95 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
	Note: More injury to cortex than to xylem.					
23	Mar. 4	Northeast side, young Gano tree no. 15	7	—35.0°	30	95 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 16, trunk tarred				85 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 17				75 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				85 per cent injury to cambium, severe to cortex and xylem
		Northeast side, young Gano tree no. 20				90 per cent injury to cambium, severe to cortex and xylem

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1915)					
23	Mar. 4	Southwest side, same tree	7	—35.0°	30	Same
		Northeast side, young Gano tree no. 23				85 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				90 per cent injury to cambium, severe to cortex and xylem
		Northeast side, young Gano tree no. 26, trunk tarred				95 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 27				85 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				90 per cent injury to cambium, severe to cortex and xylem
24	Mar. 6	Northeast side, young Gano tree no. 27, trunk tarred	5½	—32.0°	45	No injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 21				5 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 36, trunk tarred				Same
		Southwest side, same tree				50 per cent injury* to cambium, severe to cortex and xylem
		Northeast side, young Northern Spy tree no. 29				5 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				50 per cent injury* to cambium, severe to cortex and xylem
		Northeast side, young Northern Spy tree no. 30				5 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 32				Same
		Southwest side, same tree				Same
25	Mar. 10	Northeast side, old seedling tree no. 2	5½	—33.0°	30	20 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 4, trunk tarred				5 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				0.5 per cent injury to cambium, severe to cortex and xylem
		Northeast side, old seedling tree no. 8, trunk tarred				2 per cent injury to cambium, considerable to cortex and xylem
		Southwest side, same tree				Very slight injury (less than 1 per cent) to cambium, slight to cortex and xylem

* This was natural injury to pieces before freezing. More injury to cortex than to xylem.

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1915)					
25	Mar. 10	Northeast side, old seedling tree no. 11	5½	—33.0°	30	20 per cent injury to cambium, severe to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old Bellflower tree no. 9				Less than 1 per cent injury to cambium, slight to cortex and xylem
		Southwest side, same tree				2 per cent injury to cambium, slight to cortex and xylem
		Northeast side, old seedling tree no. 7				0.5 per cent injury to cambium, slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, slight to cortex and xylem
		Northeast side, old seedling tree no. 3				Same
		Southwest side, same tree				Same
Note: Cortex slightly more injured than xylem.						
25a	Mar. 10	Northeast side, old seedling tree no. 2	5½	—33.0°	30	Trace of injury to cambium, slight to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 4				No injury to cambium, slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, cortex, or xylem
		Northeast side, old seedling tree no. 8				No injury to cambium, slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, cortex, or xylem
		Northeast side, old seedling tree no. 11				1 per cent injury to cambium, slight to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old Bellflower tree no. 9				5 per cent injury to cambium, slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, slight to cortex and xylem
		Northeast side, old seedling tree no. 7				Same
		Southwest side, same tree				Same
Note: In this experiment the pieces of tissue, after being prepared, were soaked for one hour in distilled water, the excess water was blotted off with filter paper, and the pieces were then frozen along with those of lot no. 25.						
26	Mar. 13	East side, old seedling tree no. 2, 3 feet above soil	4	—23.0°	Removed immediately	3 per cent injury to cambium, slight to cortex and xylem
		Same	4½	—28.0°	15	5 per cent injury to cambium, slight to cortex and xylem
		Same	4½	—33.0°	10	12 per cent injury to cambium, severe to cortex and xylem
27	Mar. 15	East side, young Gano tree no. 20, 2 feet above soil	2½	—25.0°	30	No injury to cambium, slight to cortex and xylem
		Same	2½	—29.0°	30	Same

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1915)					
27	Mar. 15	Same	3½	—30.0°	30	Very slight injury (less than 1 per cent) to cambium, slight to cortex and xylem
		South side, young Northern Spy tree no. 28, 2 feet above soil	2½	—25.0°	30	30 per cent injury to cambium, considerable to cortex and xylem
		Same	2⅞	—29.0°	30	Same
		Same	3½	—30.0°	30	10 per cent injury to cambium, considerable to cortex and xylem
28	Mar. 18	East side, old seedling tree no. 2, 3 feet above soil	Immediate	—20.0°	90	90 per cent injury to cambium, severe to cortex and xylem
		Same	2⅝	—28.0°	30	No injury to cambium, slight to cortex and xylem
		Same	3⅛ to —30.5°	—31.0°	30 at —30.5° to —31°	Very slight injury to cambium, slight to cortex and xylem except injury to xylem next to cambium layer
29	Mar. 22	East side, old seedling tree no. 2, 2 feet above soil	Immediate	—20.0°	30	From 90 to 95 per cent injury to cambium, considerable to cortex, slight to xylem
		Same	1⅝ to —25.0°	—27.0°	30 at —25° to —27°	15 per cent injury to cambium, slight to cortex and xylem
		Same	1⅝ to —31.0°	—34.0°	30 at —31° to —34°	From 15 to 20 per cent injury to cambium, considerable to cortex and xylem
30	Mar. 24	East side, old seedling tree no. 2, 3 feet above soil	Immediate	—20.0°	30	80 per cent injury to cambium, considerable to cortex, slight to xylem
		Same	1½	—30.0°	15 at —30°, 30 at —20° to —25°	60 per cent injury to cambium, severe to cortex, slight to xylem
		Same	1⅞	—32.0°	20	75 per cent injury to cambium, severe to cortex, slight to xylem
31	Mar. 27	Northeast side, old seedling tree no. 2	6	—31.0°	30	No injury to cambium, very slight to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 4, trunk tarred				Same
		Southwest side, same tree				Same
		Northeast side, old seedling tree no. 8, trunk tarred				Same
		Southwest side, same tree				Very slight injury (less than 1 per cent) to cambium, very slight to cortex and xylem
		Northeast side, old seedling tree no. 11				0.5 per cent injury to cambium, very slight to cortex and xylem
		Southwest side, same tree				Same

TABLE 7 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1915)					
31	Mar. 27	Northeast side, young Gano tree no. 15	6	—31.0°	30	No injury to cambium, very slight to cortex and xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 16, trunk tarred				Same
		Southwest side, same tree				.....
		Northeast side, young Northern Spy tree no. 17				Very slight injury (less than 1 per cent) to cambium, very slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, very slight to cortex and xylem
		Northeast side, young Gano tree no. 20				Same
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 23, trunk tarred				Very slight injury (less than 1 per cent) to cambium, very slight to cortex and xylem
		Southwest side, same tree				No injury to cambium, very slight to cortex and xylem
32	Mar. 31	Northeast side, old seedling tree no. 4, trunk tarred	5½	—33.0°	30	No injury to cambium, very slight to cortex and xylem
		Southwest side, same tree				0.5 per cent injury to cambium, slight to cortex and xylem
		Northeast side, old seedling tree no. 8, trunk tarred				Very slight injury (less than 1 per cent) to cambium, very slight to cortex and xylem
		Southwest side, same tree				Same
		Young Northern Spy tree no. 22, 2 feet above soil				Very slight injury (less than 1 per cent) to cambium, slight to cortex and xylem
		Same tree, 4 inches above soil				No injury to cambium, slight to cortex and xylem
		Young Northern Spy tree no. 28, 2 feet above soil				15 per cent injury to cambium, slight to cortex and xylem
		Same tree, 4 inches above soil				Same
		Young Northern Spy tree no. 32, 2 feet above soil				No injury to cambium, slight to cortex and xylem
		Same tree, 4 inches above soil				Same
		East side trunk, old seedling tree no. 2, 3 feet above soil (six pieces)	5½	—29.0°	30	No injury to cambium, very slight to cortex and xylem
		Same (six pieces)	5½	—33.0°	30	Injury varied in different pieces, from no injury, to from 3 to 5 per cent to cambium, very slight to cortex and xylem
33	Apr. 13	Northeast side, old seedling tree no. 2	6	—30.0°	30	80 per cent injury to cambium, considerable to cortex, slight to xylem
		Southwest side, same tree				Same

TABLE 7 (*concluded*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1915)					
33	Apr. 13	Northeast side, old seedling tree no. 4, trunk tarred	6	—30.0°	30	85 per cent injury to cambium, considerable to cortex, slight to xylem
		Southwest side, same tree				90 per cent injury to cambium, considerable to cortex, slight to xylem
		Northeast side, old seedling tree no. 8, trunk tarred				80 per cent injury to cambium, severe to cortex, less severe to xylem
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 15				95 per cent injury to cambium, severe to cortex, less severe to xylem
		Southwest side, same tree				Same
		Northeast side, young Northern Spy tree no. 17				Same
		Southwest side, same tree				Same
		Northeast side, young Gano tree no. 23, trunk tarred				85 per cent injury to cambium, severe to cortex, less severe to xylem
		Southwest side, same tree				Same

From a study of the results of artificial freezing, it is apparent that there is no difference in degree of hardiness between the tissue on the southwest and that on the northeast side of the trunk, at least none that can be detected by the method of artificial freezing. It is true that the technique of these experiments is not sufficiently perfect to permit detecting with accuracy any very small differences, but it seems reasonable to believe that any difference so marked as to account for the occurrence of sun-scald on the southwest side of the tree would be easily detected. It is to be noted that in 1915 the freezings were continued later than there was any possibility of the occurrence of sun-scald under natural conditions. The freezings from March 6 to April 13, 1915, show that the trunk tissue was gradually becoming tenderer on both sides; on April 13 it was considerably less hardy than in February, but there was no appreciable difference in the time of this awakening from the dormant condition between the sun-exposed and the shaded side of the trunk. Further, no degree of tenderness was reached on either side great enough to allow the tissue to be killed by temperatures likely to occur in this latitude in March or April.

It seems, in view of this evidence, that Müller-Thurgau's hypothesis to account for the occurrence of sun-scald must be eliminated.

NATURAL INJURY IN THE WINTER OF 1914-15

Some natural injury to the cambium on the southwest side of the trunk was noticed during the winter of 1914-15. This may be reported briefly as follows:

Tree no. 35. Young Northern Spy. Injury to cambium, some to cortex. Injury noticed on January 25, 1915.

Tree no. 18. Young Northern Spy; space on trunk tarred October 23, 1914. On February 24, 1915, a large injured area was found extending from the base of the trunk upward for a distance of one and one-half feet on the southwest side of the tree. The injury was confined to the tarred space. The bark, the cambium, and the outer sapwood were completely killed. The bark was a dead-brown color thruout, but not yet dried out; it seems probable that the injury occurred sometime in the winter of 1914-15. Cuttings for artificial freezing had been taken from this tree at intervals all winter, but from a point a few inches above the upper limit of this injury. The injured tissue was accidentally cut into on February 24 and the injury discovered. It was not yet apparent externally.

Tree no. 26. Young Gano; space on trunk tarred October 23, 1914. Partial injury to cambium, slight injury to cortex, very slight injury to xylem, observed on February 24, 1915. This injury could be detected only by aid of the microscope. Cuttings from this tree had been previously examined at intervals, but only macroscopically.

Tree no. 25. Young Gano; space on trunk tarred November 23, 1914. Injury as described in preceding paragraph, observed on February 24, 1915. No previous examination.

Tree no. 28. Young Northern Spy. Same injury as described above observed on February 24, 1915. No previous examination.

Tree no. 43. Young Northern Spy. Same injury as described above observed on February 24, 1915. No previous examination.

Tree no. 36. Young Northern Spy; space on trunk tarred January 15, 1915. Injury 50 per cent to cambium, some injury to cortex and xylem; could be detected only microscopically; observed on March 8, 1915. Cuttings from this tree had been examined previously at intervals, but only macroscopically.

Tree no. 29. Young Northern Spy. Injury 50 per cent to cambium, some injury to cortex and xylem, observed under microscope on March 8, 1915. No previous examination.

Altho these observations are not conclusive as to the date of occurrence of the injury, yet, taken in connection with the artificial freezing work, they are interesting as showing that natural injury occurred

in 1915 before there was any possibility for the tissue on the southwest side of the tree to become tenderer.

There now remains one hypothesis to account for the occurrence of sun-scald. That is, that it may result from a rapid temperature fall consequent to the warming-up of the tissue on a cold, sunny day.

With proper conditions this point might be determined in the following manner: On a day when the tissue on the southwest side of the tree had been thoroly thawed out while that on the northeast side had remained very cold, say about −16° C., if a fairly rapid fall of temperature occurred after sundown, conditions would be proper for sun-scald provided a certain minimum temperature were reached. It seems probable that by taking tissue from opposite sides of the tree in the early morning, while it was yet at the minimum temperature for the night and without allowing it to warm up, and carrying several samples of the tissue down to different minima by the use of freezing mixture, a point might be reached at which the tissue from the southwest side would kill while that from the northeast side would not.

Such conditions are rare, and it was not possible to run this experiment during the winters of 1913-14 and 1914-15. It is believed that if the experiment could be performed it would offer conclusive evidence with regard to the hypothesis under consideration.

In the absence of such evidence something may be learned from a comparison of the effects of rapid and slow freezing. Chandler (1913), in determining the comparative effect of rapid and slow freezing, employed the winter twigs and buds of various fruit trees. It seemed worth while to run a few freezings in order to determine whether the same phenomena were apparent in the case of the tissues under discussion here — the cambium, the xylem, and the cortex from the trunk of apple trees in the winter condition.

Among the freezing experiments recorded in table 7 are some that have a bearing on this point, and of these a few deserve review here:

(a) Tissue frozen on January 28, 1914, three and one-fourth hours to −20.6° C., one-half hour at minimum, killed more severely than similar tissue (not, however, from the same tree) frozen on January 30, seven hours to −20.6° C., one-half hour at minimum.

(b) March 19, 1914, pieces of tissue from the same trees were frozen seven hours to −28° C., one hour at minimum; two and one-half hours to −18.3° C., one-half hour at minimum; severe cambium injury in both cases.

(c) March 15, 1915, tissue from a young Gano tree, no. 20, was frozen two and one-half hours to −25° C., one-half hour at minimum, with no injury to cambium; two hours and thirty-five minutes to −29° C., one-half hour at minimum, with no injury to cambium; three hours and five minutes to −30° C., one-half hour at minimum, with very slight injury to cambium and slight injury to cortex and xylem.

March 27, 1915, tissue from the same tree was frozen six hours to −31° C., one-half hour at minimum, with no injury to cambium and very slight injury to cortex and xylem.

(d) March 15, 1915, tissue from a young Northern Spy tree, no. 28, was frozen two and one-half hours to −25° C., one-half hour at minimum, with 30 per cent injury to cambium and considerable injury to cortex and xylem; two hours and thirty-five minutes to −29° C., one-half hour at minimum, with 30 per cent injury to cambium and considerable injury to cortex and xylem; three hours and five minutes to −30° C., one-half hour at minimum, with 10 per cent injury to cambium and considerable injury to cortex and xylem.

March 31, 1915, tissue from the same tree was frozen five and one-half hours to −33° C., one-half hour at minimum, with 15 per cent injury to cambium and slight injury to cortex and xylem.

(e) March 18, 1915, tissue from an old seedling tree, no. 2, was frozen immediately to −20° C., one and one-half hours at minimum, with 90 per cent injury to cambium and severe injury to cortex and xylem; two hours and fifty minutes to −28° C., one-half hour at minimum, with no injury to cambium and slight injury to cortex and xylem; three hours and ten minutes to −30.5° C., one-half hour at minimum, with very slight injury to cambium and slight injury to cortex and xylem.

March 22, 1915, tissue from the same tree was frozen immediately to −20° C., one-half hour at minimum, with from 90 to 95 per cent injury to cambium, considerable injury to cortex, and slight injury to xylem; one hour and forty-five minutes to −25° C., one-half hour at minimum, with 15 per cent injury to cambium and slight injury to cortex and xylem; one hour and fifty minutes to −31° C., one-half hour at minimum, with from 15 to 20 per cent injury to cambium and considerable injury to cortex and xylem.

March 24, 1915, tissue from the same tree was frozen immediately to −20° C., one-half hour at minimum, with 80 per cent injury to cambium, considerable injury to cortex, and slight injury to xylem; one hour and twenty minutes to −30° C., three-fourths hour at minimum, with 60 per cent injury to cambium, severe injury to cortex, and slight injury to xylem; one hour and thirty-five minutes to −32° C., twenty minutes at minimum, with 75 per cent injury to cambium, severe injury to cortex, and slight injury to xylem.

March 27, 1915, tissue from the same tree was frozen six hours to −31° C., one-half hour at minimum, with no injury to cambium and very slight injury to cortex and xylem.

March 31, 1915, tissue from the same tree was frozen five and one-fourth hours to −29° C., one-half hour at minimum, with no injury to cambium and very slight injury to cortex and xylem; five and one-half hours to −33° C., one-half hour at minimum, with very slight injury to cambium, cortex, and xylem.

In addition to the experiments described above, it may be stated that at several times during the winter, when there has been occasion to kill tissue by artificial freezing, it has always been possible to accomplish this by immediate freezing to −20° C. Also, at different times during the dormant period two-years-old apple and pear trees have been subjected to this immediate freezing by placing galvanized iron cylinders around the trunks and packing the space within with salt-and-ice mixture. In these experiments severe killing resulted in bark, cambium, and outer sapwood.

In considering these results the temperature observations of February 14, 1916, should be recalled. It will be seen by referring to table 5 (page 255) that the temperature of the tissue on the southwest side of the small tree trunk fell from −0.3° C. to −14.4° C. in one hour, in the critical part of the freezing period. While not warranting a definite conclusion, this indicates that a rate of temperature fall may occur in nature rapid enough to raise the killing point of the tissue, and suggests the probability that sun-scald may result from this condition.

RELATIVE HARDINESS OF TISSUE FROM THE CROWN AND THE UPPER PARTS OF THE TRUNK

Chandler (1913), as the result of a number of artificial freezings, concludes that the tissue at the crown, or base, of the tree becomes hardy more slowly at the beginning of the winter than does tissue from the higher parts of the tree. In the freezings reported in table 7, tissue for preliminary freezings was taken from various heights on the trunk, with the idea that this difference in hardiness would make it easier to approximate the killing point. In the earlier freezings this difference was marked, but it did not appear in the freezings of December 18 and January 19.

A few freezings were then run in order to test this point more fully, and it seemed, at least in the year 1914-15, that this greater tenderness of the tissue at the base of the trunk had disappeared by midwinter (table 7, lots 10, 13, 15, 16, 17, 19, and 20). The results of these freezings would indicate that crown injury is normally an early-winter injury. In this connection it is interesting to recall Selby's mention (referred to on page 243) of crown injury in Ohio which he believes was caused by the October freeze of 1906. Clinton (1904) describes crown injury which he believes occurred on December 9, 1903. Reddick (1912) cites weather records showing that crown injury prevalent thruout New York in the spring of 1911 and noticeable early in January probably occurred in either November or December of 1910. Chandler, however, found this difference in hardiness evident as late as March 25, in the winter of 1912-13.

A more thoro test of this point was made during the winter of 1915-16 at Geneva, New York. Tissue for these freezings was taken from a number of thirty-years-old Baldwin trees in the experiment station orchard. The results of these freezings are given in table 8. It will be seen that in these trees and in this season the difference in hardiness between the crown and the upper trunk was still evident at the end of March. Since, however, the crown tissue was noticeably hardier than it was in November, it is still entirely possible that crown injury occurs oftener in the early winter than later.

TABLE 8. RECORD OF ARTIFICIAL FREEZING EXPERIMENTS TO DETERMINE RELATIVE HARDINESS OF TISSUE OF THE TRUNKS OF TREES

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1915)					
1	Nov. 10	Tree no. 51, crown, 1 inch above soil	5½	—20.0°	15	25 per cent injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3½ feet above soil				No injury to cambium, slight to cortex and xylem
		Tree no. 52, crown, 1 inch above soil				2 per cent injury to cambium, slight to cortex, considerable to inner xylem
		Same tree, 2 feet above soil				No injury to cambium, very slight to cortex and xylem
		Same tree, 3½ feet above soil				No injury to cambium, very slight to cortex, none to xylem
		Tree no. 53, crown, 1 inch above soil				50 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, cortex, or xylem
		Tree no. 54, crown, 1 inch above soil				No injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3½ feet above soil				No injury to cambium, very slight to cortex and xylem
2	Nov. 17	Tree no. 55, crown, 1 inch above soil	5½	—22.0°	30	0.5 per cent injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3 feet above soil				No injury to cambium, slight to cortex, very slight to xylem
		Tree no. 53, crown, 1 inch above soil				10 per cent injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3 feet above soil				15 per cent injury to cambium, considerable to cortex, slight to xylem
		Tree no. 56, crown, 1 inch above soil				No injury to cambium, very slight to cortex and xylem
		Same tree, 3½ feet above soil				Same
		Tree no. 57, crown, 1 inch above soil				Same
		Same tree, 2 feet above soil				Same
		Same tree, 3½ feet above soil				Same
		Tree no. 54, crown, 1 inch above soil				Same
		Same tree, 3 feet above soil				Same
3	Nov. 23	Tree no. 54, crown, 1 inch above soil	6½	—25.0°	30	15 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 2½ feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 56, crown, 1 inch above soil				Same
		Same tree, 2½ feet above soil				Same

TABLE 8 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
3	(1915) Nov. 23	Tree no. 57, crown, 1 inch above soil	6½	—25.0°	30	75 per cent injury to cambium, considerable to cortex, slight to xylem
		Same tree, 3½ feet above soil				Same
		Tree no. 58, crown, 1 inch above soil				80 per cent injury to cambium, slight to cortex and xylem
		Same tree, 3½ feet above soil				85 per cent injury to cambium, slight to cortex and xylem
4	Dec. 3	Tree no. 60, crown, 1 inch above soil	6⅝	—27.0°	25	10 per cent injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3½ feet above soil				No injury to cambium, slight to cortex, very slight to xylem
		Tree no. 56, crown, 1 inch above soil				15 per cent injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3½ feet above soil				2 per cent injury to cambium, very slight to cortex and xylem
		Tree no. 57, crown, 1 inch above soil				50 per cent injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3½ feet above soil				30 per cent injury to cambium, slight to cortex, very slight to xylem
		Tree no. 58, crown, 1 inch above soil				50 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3½ feet above soil				Same
5	(1916) Jan. 21	Tree no. 51, crown, 1 inch above soil	6½	—28.0°	30	Severe injury to cambium, slight to cortex and xylem
		Same tree, 3½ feet above soil				2 per cent injury to cambium, slight to cortex and xylem
		Tree no. 52, crown, 1 inch above soil				Same
		Same tree, 3½ feet above soil				No injury to cambium, slight to cortex, very slight to xylem
		Tree no. 56, crown, 1 inch above soil				Same
		Same tree, 3 feet above soil				Same
		Tree no. 58, crown, 1 inch above soil				25 per cent injury to cambium, considerable to cortex, slight to xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 54, crown, 1 inch above soil				Trace of injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 55, crown, 1 inch above soil				Trace of injury to cambium, very slight to cortex and xylem

TABLE 8 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1916)					
5	Jan. 21	Same tree, 3 feet above soil	6½	—28.0°	30	Same
		Tree no. 53, crown, 1 inch above soil				Trace of injury to cambium, slight to cortex, very slight to xylem
		Same tree, 3 feet above soil				Same
6	Jan. 27	Tree no. 51, crown, 1 inch above soil	6¾	—30.0°	15	75 per cent injury to cambium, considerable to cortex and xylem
		Same tree, 3 feet above soil				2 per cent injury to cambium, very slight to cortex and xylem
		Tree no. 52, crown, 1 inch above soil				Same
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Same tree, 6 inches below soil				35 per cent injury to cambium, slight to cortex and xylem
		Tree no. 54, crown, 1 inch above soil				No injury to cambium, slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Same tree, 4 inches below soil				75 per cent injury to cambium, considerable to cortex and xylem
		Tree no. 56, crown, 1 inch above soil				45 per cent injury to cambium, considerable to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 57, crown, 1 inch above soil				25 per cent injury to cambium, slight to cortex and xylem
		Same tree, 3 feet above soil				2 per cent injury to cambium, slight to cortex and xylem
		Tree no. 58, crown, 1 inch above soil				5 per cent injury to cambium, slight to cortex and xylem
		Same tree, 3 feet above soil				Same
6a	Jan. 27	Tree no. 51, crown, 1 inch above soil	6¾	—30.0°	15	75 per cent injury to cambium, considerable to cortex and xylem
		Same tree, 3 feet above soil				5 per cent injury to cambium, slight to cortex and xylem
		Tree no. 52, crown, 1 inch above soil				25 per cent injury to cambium, considerable to cortex, slight to xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Same tree, 6 inches below soil				90 per cent injury to cambium, considerable to cortex, slight to xylem
		Tree no. 54, crown, 1 inch above soil				No injury to cambium, very slight to cortex and xylem

TABLE 8 (*continued*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1916)					
6a	Jan. 27	Same tree, 3 feet above soil	6¾	—30.0°	15	Same
		Tree no. 56, crown, 1 inch above soil				50 per cent injury to cambium, considerable to cortex, slight to xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 57, 3 feet above soil				From 2 to 5 per cent injury to cambium, very slight to cortex and xylem
		Tree no. 58, 3 feet above soil				75 per cent injury to cambium, considerable to cortex, slight to xylem
Note: In this experiment the pieces of tissue were soaked in distilled water for one-half hour before freezing. The excess water was poured off and the pieces were frozen while wet, along with those of lot no. 6.						
7	Mar. 22	Tree no. 51, base	6¾	—31.0°	15	25 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 52, base				30 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 53, base				25 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 54, base				Same
		Same tree, 3 feet above soil				Same
		Tree no. 56, base				Same
		Same tree, 3 feet above soil				Same
		Tree no. 57, base				From 2 to 5 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
8	Mar. 29	Tree no. 54, base	7 (6 hours 0 to —12°, 1 hour —12° to —32°)	—32.0°	15	40 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				20 per cent injury to cambium, very slight to cortex and xylem
		Tree no. 56, base				10 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 57, base				10 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem

TABLE 8 (*concluded*)

Lot no.	Date	Source of tissue	Length of temperature fall (hours)	Minimum reached (°C.)	Length of time at minimum (minutes)	Injury
	(1916)					
8	Mar. 29	Tree no. 58, base	7 (6 hours 0 to −12°, 1 hour −12° to −32°)	−32.0°	15	10 per cent injury to cambium, very slight to cortex and xylem
		Same tree, 3 feet above soil				No injury to cambium, very slight to cortex and xylem
		Tree no. 62, base				No injury
		Same tree, 3 feet above soil				No injury
		Tree no. 51, northeast side of trunk				No injury
		Same tree, southwest side				No injury
		Tree no. 52, northeast side of trunk				Very slight injury to cambium (from 1 to 5 per cent), very slight to cortex and xylem. No difference between opposite sides of trunk
		Same tree, southwest side				Same
		Tree no. 61, northeast side of trunk				Same
		Same tree, southwest side				Same
		Tree no. 62, northeast side of trunk				Same
		Same tree, southwest side				Same
		Tree no. 55, northeast side of trunk				5 per cent injury to cambium, very slight to cortex and xylem
		Same tree, southwest side				No injury to cambium, very slight to cortex and xylem

EFFECT OF FREEZING TISSUE WHEN WET

Macoun's (1908) explanation of crotch injury suggests that a wet or water-soaked condition of the tissue previous to freezing may increase the killing.

A comparison of the experiments reported in table 7, lots 25 and 25a, and table 8, lots 6 and 6a, shows that soaking the tissue in distilled water and freezing it while wet did not increase the amount of killing.

CONCLUSION

Sun-scald, an injury sometimes occurring to bark, cambium, and outer sapwood on the southwest side of tree trunks, particularly of apple trees, is probably a winter injury caused by direct freezing to death of the tissue. This freezing to death is, it is believed, made possible by a rapid temperature fall consequent to warming-up of the tissue above freezing by the rays of the sun on a bright, cold day in late winter.

Sun-scald seems to be a late-winter injury, as distinguished from crown rot, which is perhaps an early-winter injury; sun-scald is therefore not

induced by late growth or an unripened condition of the trees in the fall, while crown rot no doubt is. An important factor in the cause of crown rot is the lower degree of hardiness of the tissue at the base of the trunk than on the upper parts.

A practical method of preventing sun-scald is to spray or paint the trunks with whitewash in fall or early winter. This is not a new recommendation, since it has been suggested by Müller-Thurgau, in 1886, and by various other writers since that time. It seems, however, that it is a more feasible method than other recommendations that have been made, such as shading the trunk with a board or with brush. It seems worthy of a trial, especially in northern regions where sun-scald is a not uncommon type of winter injury. Of course this injury is one that occurs only in certain years, usually with a considerable intermediate period of immunity, so that it is not probable that this method will ever come into wide use. It would obviously be employed many times unnecessarily for once when it was necessary.

LITERATURE CITED

The following is a list of the publications to which reference is made in the text. For a complete bibliography of the subject of the killing of plant tissue by low temperature, the reader is referred to the paper by Chandler, the title of which is given below.

BROWN, H. P. Growth studies in forest trees. I. Pinus rigida Mill. Bot. gaz. **54**: 386–403. 1912.

BURRILL, THOMAS J. Climatal destruction of orchard trees. Univ. Illinois. Rept. **13**: 283–293. 1887.

CHANDLER, W. H. The killing of plant tissue by low temperature. Missouri Agr. Exp. Sta. Research bul. 8: 141–309. 1913.

CLINTON, G. P. Winter injury. *In* Report of the Botanist. Connecticut (New Haven) Agr. Exp. Sta. Ann. rept. **27** (1903): 303–304. 1904.

———— Winter injury. *In* Report of the Botanist. Connecticut (New Haven) Agr. Exp. Sta. Ann. rept. **28** (1904): 312–313. 1905.

———— Collar girdle and root injury [of peach]. *In* Report of the Botanist for 1908. Connecticut (New Haven) Agr. Exp. Sta. Ann. rept. **31–32**: 856–857. 1908.

GOEPPERT, H. R. Ueber die Warmeentwickelung in den Pflanzen; deren Gefrieren und die Schutzmittel gegen Dasselbe, p. 1–273. 1830.

GROSSENBACHER, J. G. Crown-rot, arsenical poisoning, and winter injury. New York (Geneva) Agr. Exp. Sta. Tech. bul. 12: 369–411. 1909.

———— Crown-rot of fruit trees: field studies. New York (Geneva) Agr. Exp. Sta. Tech. bul. 23:1–59. 1912.

HARTIG, R. Bark-scorching, sun-cracks, and deficiency of light. *In* Text-book of the diseases of trees, p. 294–299. (English translation by William Somerville and H. Marshall Ward.) 1894.

———— Schädliche Einwirkungen der Wärme. *In* Lehrbuch der Pflanzenkrankheiten, 3d ed., p. 228–233. 1900.

MACOUN, W. T. Winter injury to fruit trees — Ten different ways in which trees are affected. Canadian Exp. Farms. Rept. **1908**:110–116. 1908.

MOLISCH, HANS. Untersuchungen über das Erfrieren der Pflanzen, p. 1–73. 1897.

MORSE, W. J. Notes on plant diseases in 1908. Maine Agr. Exp. Sta. Bul. 164:1–28. 1909.

MÜLLER-THURGAU, HERMANN. Ueber das Gefrieren and Erfrieren der Pflanzen. I Theil. Landw. Jahrb. **9**:133–189. 1880.

———— Ueber das Gefrieren und Erfrieren der Pflanzen. II Theil. Landw. Jahrb. **15**:453–610. 1886.

REDDICK, D. Frost injury. New York State Fruit Growers' Assoc. Proc. **1912**:34–41. 1912.

SACHS, JULIUS. Krystallbildungen bei dem Gefrieren und Veränderung der Zellhäute bei dem Aufthauen saftiger Pflanzentheile. Kön.-Sächs. Gesell. Wiss. Leipzig. Math.-Phys. Cl. Ber. Verh. **12**:1–50. 1860.

SELBY, AUGUSTINE D. Some diseases of orchard and garden fruits. Ohio Agr. Exp. Sta. Bul. 79:97–141. 1897.

———— A condensed handbook of the diseases of cultivated plants in Ohio. Ohio Agr. Exp. Sta. Bul. 121:1–69. 1900.

———— Fall and early winter injuries to orchard trees and shrubbery by freezing. Ohio Agr. Exp. Sta. Bul. 192:129–148. 1908.

SORAUER, PAUL. Sonnenrisse. *In* Handbuch der Pflanzenkrankheiten, 3d ed. **1**:644. 1909.

STEWART, F. C., ROLFS, F. M., AND HALL, F. H. A fruit-disease survey of western New York in 1900. New York (Geneva) Agr. Exp. Sta. Bul. 191:291–331. 1900.

WINKLER, ALBERT. Über den Einfluss der Aussenbedingungen auf die Kälteresistenz ausdauernder Gewächse. Jahrb. wiss. Bot. **52**:467–506. 1913.